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OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

EDITOR

C. A. CHANT
University of Toronto, Toronto

ASSOCIATE EDITORS

W. F. KING
Chief Astronomer
Ottawa

R. F. STUPART
Director of the Meteorological
Service of Canada, Toronto

J. S. PLASKETT
Dominion Observatory
Ottawa

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Editorial communications should be addressed to C. A. Chant, University of Toronto, Toronto, Ont.

Business correspondence, remittances, etc., should be addressed to Chas. P. Sparling, Treasurer of the Society, 198 College Street, Toronto.

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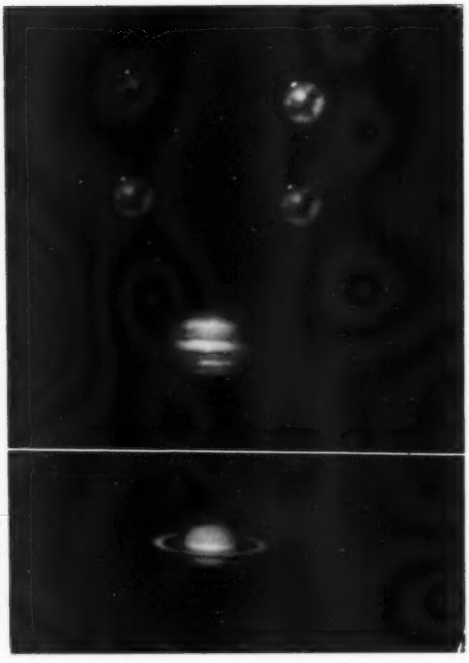
PLATE VIII.

I.

II.

III.



PHOTOGRAPHS OF THE PLANETS

I. MARS, Syrtis Major Region. By E. E. Barnard, with the 40-inch Refractor, Yerkes Observatory. September 28, 1909, 16h 4m. G.M.T.

II. JUPITER, by E. E. Barnard, 40-inch, October 2, 1906.

III. SATURN, by E. C. Slipher, Lowell Observatory, November 4, 1909.

(I. was obtained from a positive kindly supplied by Professor Barnard. II. and III. are from lantern slides made at the Yerkes and Lowell Observatories, respectively; in these some detail has been lost in making the print.)

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LIFE ON OTHER WORLDS*

BY R. G. AITKEN

ONE of the heresies for which the monk Giordano Bruno suffered martyrdom in the year 1600 is said to have been the doctrine that there were other inhabited planets besides our Earth. This was before the telescope was invented, and Bruno's conclusions must have been reached by the exercise of pure reason or of faith, for nothing whatever was known by observation about physical conditions in other worlds. I cite this instance to show that the question "Is there life in other worlds?" is one that has appealed to men in all ages, to the philosopher and the theologian quite as strongly as to the astronomer. Indeed, among the most prominent names in the literature of the subject we find Kant, Swedenborg, Brewster, Whewell and Alfred Russel Wallace, not one of them a professional astronomer.

My experience in the past sixteen years in helping to entertain visitors on public nights at the Lick Observatory has con-

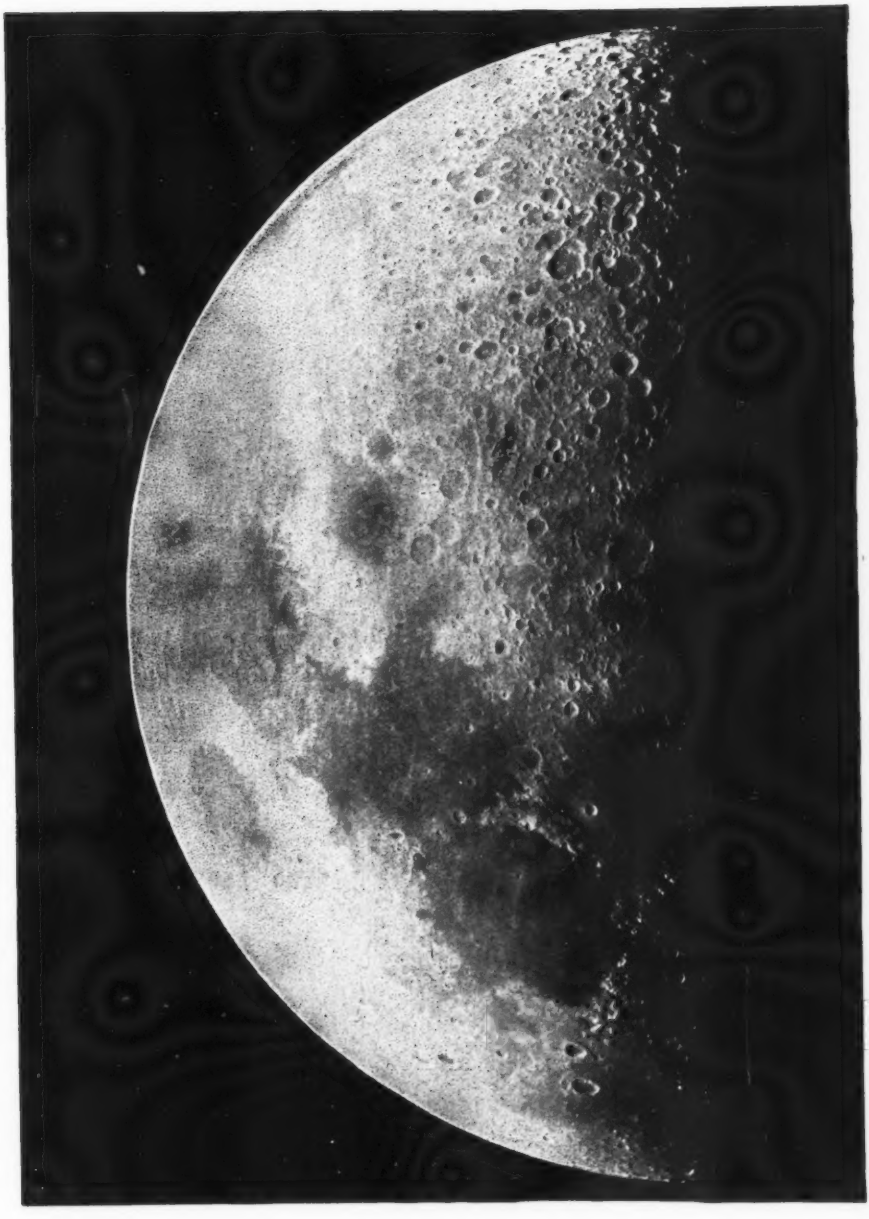
*An address delivered before the Royal Astronomical Society of Canada at Toronto, January 23, 1911.

vinced me that the question still appeals to every one whose range of thought is wider than the round of his immediate daily activities, for, in one form or another it is asked by some visitor on every night. Our observatory, indeed, is said to owe its being in large part to the hope James Lick had that by means of a telescope more powerful than any then in existence the presence of life on other planets might be detected.

In presenting this world-old question to you this evening, it is my purpose to review as impartially as possible the evidence that has been accumulated by observations with modern telescopes and their powerful accessories, the camera and the spectroscope, and to see whether or not this evidence is sufficient to justify us in drawing definite conclusions. But, first, it is essential to get a clear idea of the question itself. What do we mean by life in other worlds, or by life itself. It is unnecessary to attempt a definition of the word "life"; it will suffice to remind you that the term covers an almost infinite variety of forms, from the microbe to the mastodon, from the simplest unicellular structure to the complex organism of the human body. When we read the past history of the Earth in the record written in its crust we find that our planet in bygone ages was the habitat of innumerable forms of plants and animals that would be as strange to us to-day as Mr. Wells' conceptions of Martian life. We must then divest our minds of prejudice in favor of forms of life familiar to us, for there is no reason whatever to assume that life, even intelligent life, on other worlds must be cast in terrestrial moulds.

Again, whatever our views may be as to its origin,— whether we believe in a special creation, in spontaneous generation, or in spores blown to us by light pressure from some unknown world in space,— I think we all agree that life began upon the Earth as soon as the conditions were favorable, and that it began with the simplest forms, and developed into its present myriad forms by an evolution requiring millions of years. In this long period the Earth's surface features have suffered many great changes, involving tremendous variations of

PLATE IX.



THE MOON

From a photograph taken at the Paris Observatory, March 14, 1894

Journal of the Royal Astronomical Society of Canada, 1911

climate. That life has, nevertheless, maintained itself and proceeded in its evolution argues that the production and protection of life is one of Nature's chief cares. We may, therefore, expect to find life on other worlds as soon as the conditions there are favorable to its appearance, though the forms it assumes may be far removed from those familiar to us here.

What are the conditions that favor the production of life? Briefly stated, they are, for terrestrial life, water in liquid form, air, a few salts, and a moderate mean temperature without too great a range. In thinking of life in other worlds we must of necessity limit ourselves to forms to which the same conditions are essential. If you insist that there may be forms of life that can actively exist in the furnace of the Sun, or on frozen worlds, chilled with the cold of interstellar space, or on worlds destitute of air and water, I can only say that this is a subject on which we cannot reason. It transcends all human experience, and speculation in regard to such organisms is as idle as theories would be in regard to the genetic relationship of the Jabberwock in Lewis Carroll's delightful nonsense rhyme.

The spectroscope has long ago taught us that the chemical elements known in our laboratories are spread throughout the universe. We may, therefore, reasonably assume that the elements essential to vegetable and animal life on the Earth are not lacking on the other planets and may limit our present investigation to the questions as whether or not these planets also possess an atmosphere, water, and a moderate temperature.

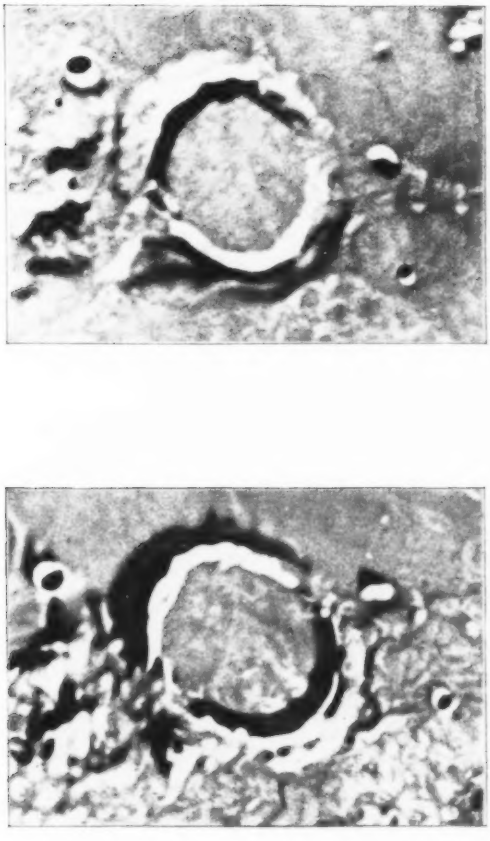
Let us look, first of all, at our nearest neighbor in space — the Moon. Examine any number of good photographs taken of the Moon, from the early experiments by De la Rue and Dr Draper to the large scale views published by the Paris Observatory. Or, better, study the lunar surface with any good telescope, even the largest. Whether we look at the limb, the terminator or at any portion between, the surface detail is always seen distinctly and without distortion and the shadows are uniformly black. We conclude, therefore, that there are no clouds upon the Moon. The natural inferences would follow: if no

clouds, then no water and probably no atmosphere, and hence no life; the Moon is a dead world.

Other evidence, direct and indirect, justifies these inferences. Thus, when the Moon occults a star, the latter disappears instantaneously. If the Moon were surrounded even with a very tenuous atmosphere this would not be the case. The star's light would fade out gradually. In fact, in one or two instances when a star was observed not to disappear instantly, the inference was drawn that it had a faint and hitherto unknown companion and this inference was verified by later observation. The quality of the star's light, at the moment of occultation, is unchanged as is shown by spectroscopic observations. Such observations also indicate that the spectrum of moonlight is identical with that of sunlight, showing no evidence whatever of passage through a lunar atmosphere, but this test is not a very sensitive one.

Again, from the kinetic theory of gases and the known mass of the Moon we can calculate the molecular velocities of the various gases, and the vertical velocity a molecule of gas on the Moon must possess to escape into outer space. We find that if the Moon were to be given an atmosphere like our own by far the greater part of it must in a relatively short time escape from its gravitative control and the residual gases, if any, would form so rare an atmosphere that liquid water could not exist on the lunar surface. It would immediately evaporate and, in the process, freeze and be deposited as hoar frost.

Finally, there is almost no evidence of any observed changes on the Moon's surface that is worthy of credence. The *appearance* of any particular crater or other feature varies with the Moon's phase, that is, with the angle of illumination by the Sun's light, as is apparent from the two views of the crater Archimedes, and such changing appearances have often deceived observers. The great majority of supposed changes that have been reported may be thus explained. In a few instances, notably in the craters Linné and Eratosthenes, actual changes seem to be established, and some astronomers



ARCHIMEDES

Drawn by Professor L. Weinek, from negatives taken in the focus of the 36 inch refractor of the Lick Observatory, August 15 and 27, 1888.

think that here low forms of vegetable life may be sustained by water-vapor exuding through crevices from the Moon's interior. But even if this explanation proves to be correct, we must still conclude that the Moon is practically a dead world.

The Moon, however, is not a planet, it may be said, but a satellite. This is true, in a sense, but it has seemed worth while to present the evidence relating to its atmosphere in some detail, because the Moon is so much nearer to us than any of the planets that we can study its surface far more minutely. It is also unique among the satellites of the solar system in the ratio its size bears to that of its primary. It is really more nearly a companion than a satellite. But let us consider the planets themselves.

PLANETARY STATISTICS

	Mean Distance	Sidereal Period	Inclination of Orbit	Eccentricity	Light and Heat from Sun	Satellites
Mercury	0·39	0·24 years	7° 0′	0·206	6·80	0
Venus	0·72	0·62	3 24	0·007	1·90	0
Earth	1·00	1·00	0 0	0·017	1·00	1
Mars	1·52	1·88	1 51	0·093	0·44	2
Jupiter	5·20	11·86	1 19	0·048	0·04	8
Saturn	9·54	29·46	2 30	0·056	0·01	10
Uranus	19·19	84·02	0 46	0·047	0·003	4
Neptune	30·07	164·78	1 47	0·009	0·001	1

	Rotation Period	Equatorial Diameter	Surface	Volume	Mass	Density	Surface Gravity at Equator
Mercury	88 days ?	0·37	0·14	0·05	0·05+	1·04	0·39
Venus	225 ?	0·97	0·93	0·89	0·81	0·91	0·85
Earth	1	1·00	1·00	1·00	1·00	1·00	1·00
Mars	1·026	0·53	0·28	0·14	0·11	0·79	0·38
Jupiter	9·8 hours	11·34	116·9	1264·0	314·5	0·25	2·39
Saturn	10·2	9·25	83·3	759·8	94·1	0·13	1·06
Uranus	?	3·94	15·9	63·4	14·4	0·23	0·93
Neptune	?	4·43	18·9	82·3	17·0	0·21	0·85

Here is a table giving some planetary statistics that have resulted from long continued observations. Inspection of it shows that we may readily divide the eight planets into two groups, usually designated as the group of minor or terrestrial planets, Mercury, Venus, the Earth and Mars; and the group of outer or major planets, Jupiter, Saturn, Uranus and Neptune.

The differences between the two groups are marked. Those which most concern us at present are (1) the differences in mean distance from the Sun and in the consequent amount of light and heat received from the Sun upon a given surface and (2) the differences in volume and mass and consequently in density.

The four inner planets, it will be seen, because they are so near the Sun, receive far more light and heat, per unit area, than do the major planets; and the latter, though vastly larger, have on the average, less than ¼ the density of the former. These differences are of great importance in connection with our investigation.

Jupiter is the largest of the planets and, viewed through a large telescope under good observing conditions, is a magnificent object. As the accompanying illustrations show, the most striking surface features are the belts of dark band-like markings that encircle it. We also notice that the disk is not round, but greatly flattened at the poles and that it darkens toward the limb. These characteristics are shown both by the drawings and by the photographs, though it is clear that the best photographs so far obtained cannot compare with the drawings in the fineness and amount of detail exhibited. Careful study of the belts and markings shows that Jupiter is rotating on its axis very rapidly — one complete rotation in 9·8 hours — also, that the different spots and markings give values for the rotation time, differing by several minutes, showing that they are in motion relatively. If two neighboring spots near the equator give rotation times differing by only three minutes, the one must be passing the other at a speed of more than 2 miles per minute.

Now these facts — the large size, the rapid rotation, the violent winds, the low density, the darkening toward the limb — all tell us something of the physical condition of the planet. It must possess a dense gaseous outer layer of considerable depth to cause the darkening of the limb; the belts and markings must be phenomena somewhat analagous to clouds in our atmosphere, spread out into bands paralleling the equator because of the great velocity of rotation. But they cannot, in any great degree, be

PLATE XI.

JUPITER

As seen with the 36-inch refractor of the Lick Observatory.
Drawn by J. E. Keeler.

due, as our clouds are, to the action of the Sun's heat upon water, for Jupiter receives, area for area, as our table shows, only $\frac{1}{25}$ as much solar heat as we do. They must be mainly clouds, or flocculi, raised by the planet's own heat. In fact we may consider Jupiter to be a semi-sun, or, at least, to resemble the Sun more nearly than it does a planet like our Earth. It is, probably, gaseous throughout, with matter distributed according to laws of density similar to those prevailing on the Sun. In any event it is reasonably certain that it does not possess a well-defined surface or crust, like the lithosphere of the earth, surrounded by an atmosphere in the terrestrial sense of the word. The adjective generally used to describe the conditions upon the planet is *chaotic*. Obviously, in such a world, there can be no question of life. Whatever may be true hereafter, we may safely say that Jupiter is not now the abode of life.

In the telescope, Saturn, the outermost planet known to the ancients, is indescribably beautiful. The illustrations, from drawings and photographs, do it but feeble justice. One is greatly tempted to digress from the subject under discussion and to describe it at length, dwelling particularly upon that unique feature, the Ring System. It must suffice, however, simply to call attention to its beauty. You will note again that the photographs, while verifying the main features shown by the drawings, do not compare with the latter in the detailed structure shown.

Our table of statistics shows that Saturn is next to Jupiter in size, and rotates nearly as rapidly; also, that it is but little more than half as dense as Jupiter. Study of the surface with the telescope further proves, as our illustrations show, that the disk darkens toward the limb, like Jupiter (and like the Sun) and that it is even more oblate (*i. e.* flatter at the poles) than the latter. The markings on the surface are, in a general, way, similar on the two planets, though not so conspicuous on Saturn, in part, no doubt, because of its greater distance. Considering all these facts there is little doubt but that, in its physical conditions, Saturn resembles Jupiter; indeed, it is probably

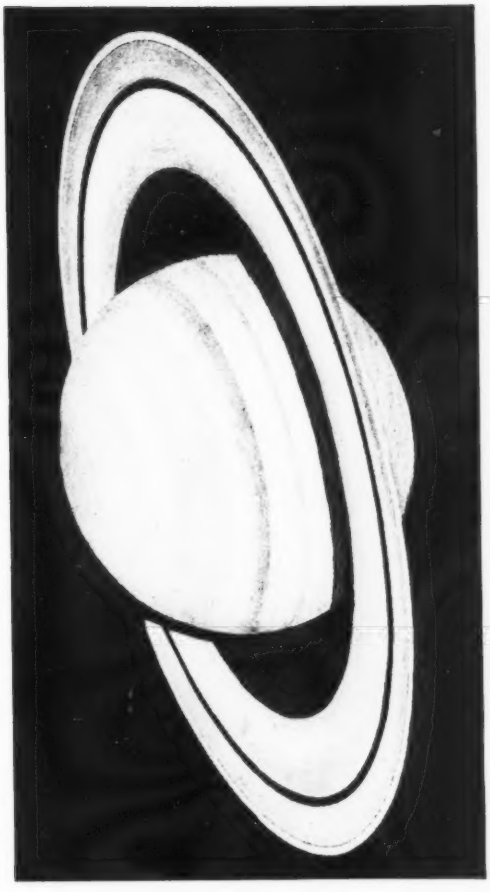
not so far advanced, and even less fitted than its larger neighbor to be the abode of life.

Little is known of the surface features of the two outer planets, Uranus and Neptune. Because of their great distance, they present but minute disks even when viewed with the most powerful telescopes. Vague surface markings have from time to time been reported and, doubtless, seen, but their observation has not yet made it possible for us to determine the rotation periods with any certainty. We know that they are so far from the Sun that its light and heat can hardly be effective in protecting life upon these planets, should it in any way originate there. We also know that they have densities intermediate between that of Jupiter and that of Saturn, and we may reasonably infer that in their physical conditions they resemble the two larger planets. This inference is supported by a study of the comparative spectra of the four major planets as shown in the illustration taken from Slipher's photographs at the Lowell Observatory. So far as this evidence goes it indicates that even deeper and denser gaseous envelopes than those of Jupiter and Saturn surround the two outer planets.

It is on the basis of such evidence as has been outlined briefly here, that astronomers unanimously agree that the major planets are destitute of life. They are not dead worlds in the sense in which we apply that appelation to the Moon, they are rather planets still in the making. Whether or not they may hereafter become the abode of life is a question on which we may speculate if we please, but not with any great profit.

A word may be said here regarding the larger satellites of these planets, especially the four brighter satellites of Jupiter, and Titan, the largest Saturnian satellite. In size these bodies are, at least, equal to our own Moon and two of them are probably larger than the planet Mercury. Very little is known of the surface features of these bodies, and our knowledge of their physical condition is correspondingly vague. Some of them seem to be of the same general density as their primaries, others more dense. If any one of them is sufficiently dense to have a

PLATE XII.



SATURN

From a drawing by J. E. Keeler, January 7, 1888

solid crust, it is possible that it may also have water and an atmosphere, and it is conceivable that this atmosphere may be of such a nature that it will retain enough of the heat received by the satellite from its primary and from the Sun, to create a moderate temperature. In this case it may be fitted to be the abode of life. This is merely conjectural at best and not very probable, but at the same time we have no evidence to warrant us in saying definitely that it is impossible.

Let us now turn to the terrestrial planets, and consider the innermost first. Mercury is well called the exceptional planet. It is the smallest, the densest and the nearest to the Sun, receiving nearly seven times as much light and heat from it, area for area, as we do. In these respects, and in others, it stands at the other extreme from the planets we have been considering. Because its orbit about the Sun lies wholly within the orbit of the Earth, we can never have the planet high in the sky at night. At sunset, under the most favorable conditions, it is low in the western sky, and when farthest west of the Sun, it is still low in the east at sunrise. Hence, until recent years little or nothing was known of its surface features, for our atmosphere, troublesome enough at best to the astronomer, interferes especially with our study of objects near the horizon.

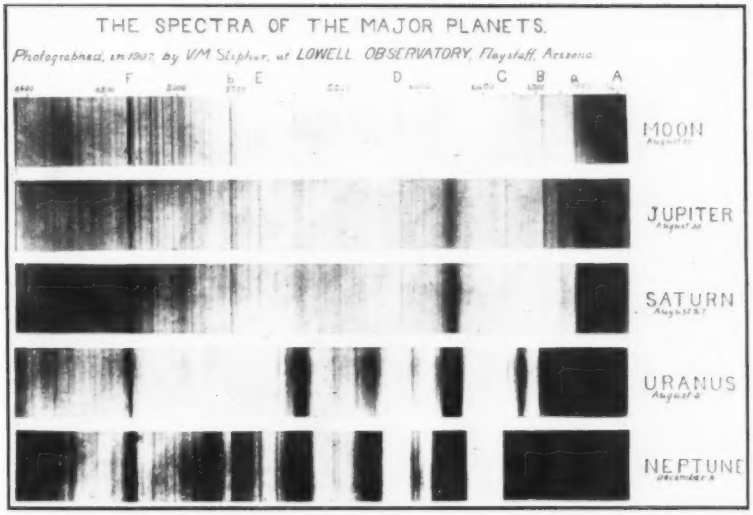
But Schiaparelli, some thirty years ago began to study this planet (and Venus, which is similarly placed though not quite so unfavorably as Mercury) by daylight when it was high in the sky. By taking suitable precautions he was able to make reliable observations under these conditions from which he concluded that Mercury always keeps the same face turned toward the Sun. That is, the planet turns on its axis just once in one revolution about the Sun, resembling in this the Moon's motion with respect to the Earth. Other observers, and especially Lowell, at Flagstaff, have confirmed Schiaparelli's results — Lowell, indeed, publishing a drawing showing an extraordinary amount of detail, little or none of which has been seen elsewhere. (See Plate XIV).

If this conclusion is correct, and I think it is now generally

accepted by astronomers as, at least, probable, it follows that the little planet is not fitted to be the abode of life. Consider the fact that it receives almost seven times as much heat as does the Earth, and imagine the conditions upon that portion of the planet which is in perpetual sunshine! Equally inhospitable would be the part where night is eternal, for it must be cold beyond human conception. Our table of statistics shows that Mercury's orbit is the most eccentric of all the planetary orbits, and in consequence of this and of its uniform axial rotation, it follows that, if its day and year are identical, a considerable part of the planet will be for a time in the sunlight, and then for a time lost in darkness. That is, the planet will have a libration similar to that of the Moon, but greater in amount. But in this borderland the range of temperature must be enormous and it is hardly conceivable that any form of life could withstand the terrible alternate roasting and freezing to which it would there be subjected.

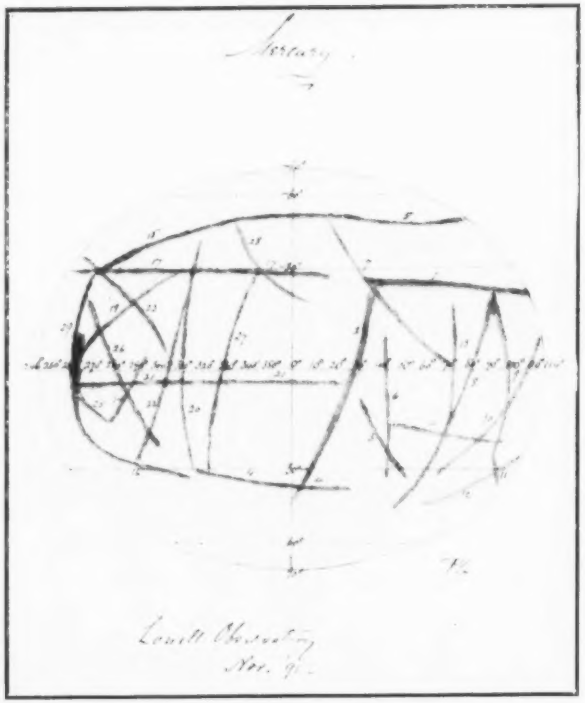
If we assume that the planet has a day approximately equal to our own in length, it is still doubtful whether it is habitable. Its mass is so small that, on the kinetic theory of gases, it could probably retain none of the lighter gases, and direct observation shows that its atmosphere, if any exists, must be very slight in amount. For example, when the planet transits the Sun, as it does at definite intervals, no ring of light is seen surrounding its disk as it enters the Sun's limb. Again, its reflecting power or albedo, is less than that of the Moon.

Very different is the aspect of things on the planet Venus. At the time of its rare transits across the Sun, it shows unmistakeable evidence that a dense atmosphere surrounds it. Its albedo, too, is very high, higher even, according to some recent observations, than the reflecting power of clouds. Astronomers all agree that Venus does not lack an atmosphere. On the contrary, the majority believe that we never see the surface of the planet itself because the cloud-filled atmosphere hides it. Our table, too, shows that the planet in size, mass, density, and surface gravity closely resembles the Earth; indeed, it is often



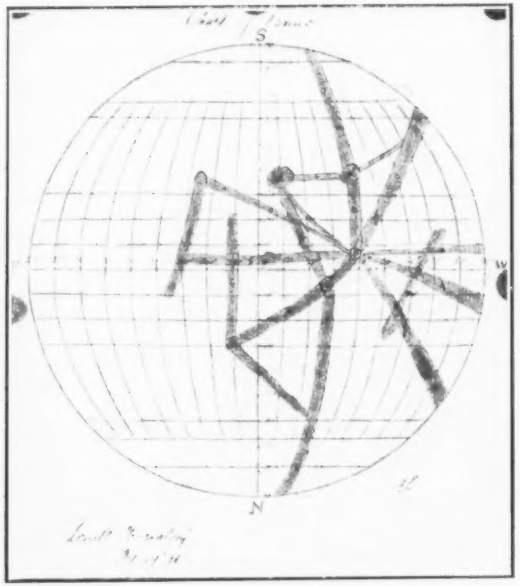
SPECTRA OF THE MAJOR PLANETS

By E. C. Slipher, Lowell Observatory *Bulletin*, No. 42.



MERCURY

Drawing by Percival Lowell.
From *Popular Astronomy*, Vol. IV., p. 300, January, 1897.



VENUS

Drawing by Percival Lowell. From *Popular Science Monthly*, Vol. LXXV., p. 530, December, 1909

(The contrast is much more intense in this reproduction than in the original. Lowell describes the markings as "faint but unmistakeable.")

called the Earth's twin planet. Circling about the Sun, not very far inside the Earth's orbit, it receives abundance of light and heat, but yet not so much as to make its probable temperature excessive, *if, in length, its day, or rotation period, is approximately equal to our own.*

This, for the planet Venus, is the critical point in our present investigation. If it rotates on its axis once in about 24 hours, we have reason to believe that it is habitable, for the conditions we named as essential to life — air, water in its liquid form and a moderate temperature — are undoubtedly realized. But if its day equals its year, then it must be utterly desolate. It will not even have a borderland between the regions of perpetual day and everlasting night, for its orbit is so nearly circular that the libration will be insignificant. The daylight side, indeed, will not be as hot as that of Mercury, but it will be equally devoid of water or water-vapor, for this must long ago have been swept by fierce atmospheric currents to the frozen side of the planet and there left as ice.

From the study of the surface markings, which were found to be vague and indistinct, Schroeter and other early observers concluded that Venus rotated once in about 23·4 hours. This was generally accepted as the fact, until Schiaparelli announced, as the result of his daylight studies, that the planet rotated only once in a revolution. More recently Mr. Lowell, following Schiaparelli's plan of daylight observation, has confirmed the longer period. The illustration shows the markings as he sees them. Like the markings on Mercury, these have not been confirmed by observation elsewhere. Other recent observers of the planet incline to the shorter period.

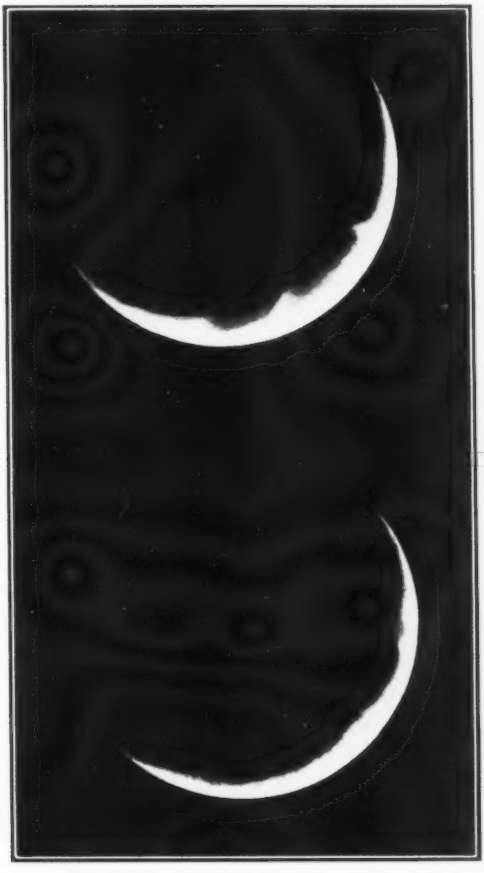
The spectroscope furnishes an independent method of measuring the rotation time of a planet, because it enables us to measure the velocity in the line of sight of any source of light. In the case of a rotating planet one limb will be moving toward the Earth, relatively to the motion of the centre of the disk, the other away from the Earth. If, then, the slit of the spectroscope be set perpendicular to the axis on which the

planet turns, the little spectral lines will all be tilted, the ends due to the light from the approaching limb being shifted slightly toward the violet, those from the receding limb toward the red end of the spectrum. If the motion of rotation is rapid enough to make this tilt or angular displacement measurable, then we can determine the rotation time. Professor Keeler utilized this method to prove, by observation, that Saturn's Rings are not continuous solids (or fluids) but aggregations of countless small bodies, satellites, each moving in its independent orbit about the planet. He showed that the inner edge of the Ring was travelling faster than the outer, and every part of it with a velocity appropriate to that of a satellite at the corresponding distance from the planet's centre. By this method, also, the rotation periods of Saturn and Jupiter and of the Sun have been confirmed.

Belopolsky, the Russian astrophysicist, applied the method to the planet Venus some years ago and announced that his results confirmed the short rotation period. Slipher, at Flagstaff, has repeated the observations more recently, and has concluded that the rotation time is very slow, certainly several months long. This may be considered confirmation of the longer period. Mr. Lowell has published Slipher's results and his own in the *Popular Science Monthly* for December, 1909. He presents his argument in detail, and concludes, from observations and from theoretical considerations, that the equality of Venus's day and year is certainly established, and that this fact is most significant in cosmogonic theory. On the other hand, Dr. See, in an article in *Sunset*, for January, 1910, argues strongly for the shorter period and finds in it strong support for his theories of planetary evolution. In his more recent volume* he writes: — "It is really not possible that the rotation period can be identical with the sidereal revolution."

From these statements it may be inferred that the question is still an open one, though the evidence rather favors the longer period; and this, I believe, is the general opinion among astro-

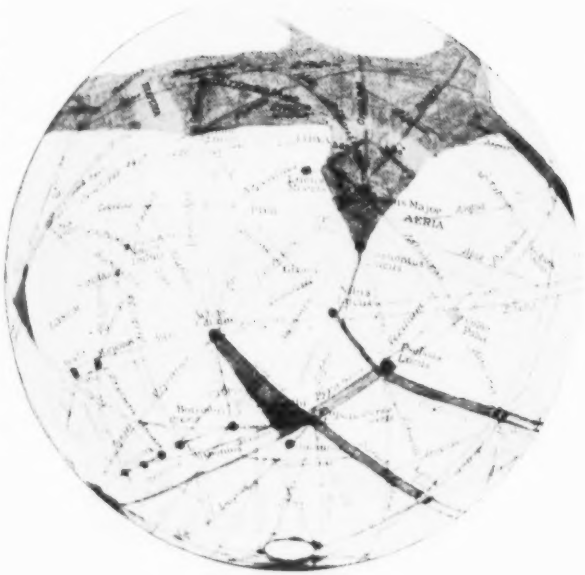
**Researches on the Evolution of the Stellar Systems*, Vol. II.



THE PLANET VENUS

As observed by E. E. Barnard with the 12-inch Refractor of the Lick Observatory, May 29, 1889.

(From "Researches on the Evolution of Stellar Systems," by T. J. J. See, Vol. II.).



PHOTOGRAPH OF A GLOBE OF MARS

By Lowell. From Plate XI, *Annals* of the Lowell Observatory, Vol. III. ($\lambda = 270$).

MARS

Drawn by E. M. Antoniadi, November 5d 8h 6m G.M.T. 32·7-inch Meudon Refractor, power 320. $\omega = 197°$; $\varphi = -23''{\cdot}6$.

PLATE XVI.

nomers. Until it is definitely settled the habitability of Venus must remain in doubt.

There remains the planet Mars. It is with this planet that the question of life in other worlds is most directly associated, the form in which it is most often put to us by our visitors being, "Do you think Mars is inhabited?" So much has been said and written about this planet on both sides of our question that a very brief summary will suffice here.

In the first place we know that, in length and in their succession, the Martian day and night correspond very closely to our own. The Martian seasons, too, resemble our own in every particular except that they are nearly twice as long. The planet has a rare atmosphere, whose surface density originally was probably not more than $\frac{1}{7}$ that of our own at sea level, and is now much less. That is, the Martian atmosphere is far more rare at the surface of the planet than our own is above our highest mountain tops. This is admitted by all. It is also agreed that there are no permanent bodies of water on the planet and that the entire amount of water existing there is very small — probably not enough to fill one of our Great Lakes. The polar caps, however, are generally accepted as evidence that some water is present, for in their appearance and in the phenomena of their seasonal change, they resemble thin deposits of snow or hoar frost. It has been argued, indeed, but with far less probability, that they may be of different composition—carbon-dioxide for instance.

Finally, it is admitted that we can see the actual surface of the planet, only slightly veiled by the thin atmosphere, and that there is an objective basis for the complex markings shown by all drawings and photographs. At times, as for example during the 1909 opposition, large areas appear to be somewhat obscured, as if by dust particles in the Martian atmosphere, but in general, the surface details are readily seen, and there are only rare observations of clouds.

We can make no definite statement as to the mean temperature on Mars, for while we can calculate with precision the rela-

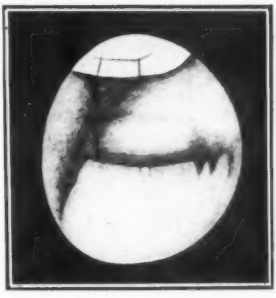
tive amount of solar heat received, we cannot know how the planet radiates heat until we know the composition of its atmosphere. A slight increase in the percentage of water-vapor or of carbon-dioxide relatively to the amounts in our own air would greatly increase the "blanketing" power of its atmosphere. Now spectroscopic observations — particularly Campbell's comparative study of the spectra of the Moon and Mars, from plates taken by him in 1909, on Mt. Whitney, under most favorable conditions, and the results of the application of Doppler's principle by Campbell and Albrecht to plates of Mars taken early in 1910, with a grating spectroscope attached to the 36-inch refractor — have shown definitely that the amount of water-vapor on the planet is too small to be detected by direct observation, and probably much less than that present in the upper strata of our own air. It is fair to assume, then, that the Martian temperature is not increased by a large percentage of water-vapor in its atmosphere; but of the carbon-dioxide or other gases that may be present we can say little. It is, perhaps, legitimate to assume that the mean temperature, while much lower than that on the Earth, is not so low that life is impossible. If this is true then we have on Mars, *to a limited extent*, the conditions essential to life; some water, a very rarified atmosphere, and a not impossible temperature. Before we draw more definite conclusions let us examine the surface markings.

To see the observations in their greatest contrast, examine first the reproductions of Mr. Lowell's recent drawings of the planet as seen at Flagstaff and then those based on M. Antoniadi's studies at the opposition of 1909 at Meudon, France. Mr. Lowell shows us a disk covered with a perfect network of "canals," which in his own words are "narrow, regular lines of even width throughout, running with geometric precision from definite points to another point where an oasis, ("a small round, dark spot") is located." Elsewhere he speaks of the canals as being so straight that, in a drawing, they must be put in by the aid of a ruler, a free hand line not being straight or uniform enough. Again, they follow great circle arcs, and, it is clear

PLATE XVII.

MARS

May 8, 1909. Drawing by Lowell.

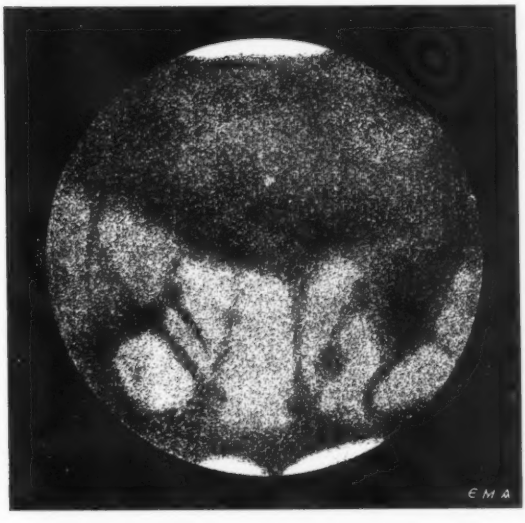


MARS

May 8, 1909.

Drawing by E. C. Slipher

From Lowell Observatory *Bulletins*, Nos. 39 and 40.



MARS

Drawing by E. M. Antoniadi

"Showing all trustworthy details visible on photographs of the planet taken by Professor Lowell on July 11, 1907, $\omega = 250°$."— *Monthly Notices*, R. A. S., Vol. LXIX., p. 111, 1908-9.

PLATE XVIII.

ERATOSTHENES

Drawn by W. H. Pickering, August 1, 1901. Age 8·6 days.
From H. C. O., Vol. LIII., No. 4, Plate I.

from the illustrations, disregard all inequalities of surface, if such exist, and sometimes extend almost half around the planet. M. Antoniadi's drawings, on the other hand, show not the slightest trace of this "geometrical network," and he does not hesitate to affirm that it does not exist. His drawings show a vast amount of fine detail, however, some of it as fine as any of the canals, but its chief characteristic is its irregularity. There are canals, too, but they differ from Mr. Lowell's in being less sharp, less uniform in width, and in being shorter. In other words they have a more natural and less artificial appearance.

Now these two observers are both skilled and experienced, and they worked with good telescopes of large size under good conditions. Doubtless, the general observing conditions at Flagstaff may be better than those at Meudon, but there must be some good nights at the latter place, and M. Antoniadi specifically states that it was when the seeing was at its best he saw the finest detail and the least trace of the geometrical network. The results of each observer are more or less completely corroborated by those of other trained observers.

Nor are the photographs more accordant. On the one hand we have here a drawing made by Mr. Lowell from the Flagstaff photographs of 1909, which shows the network of canals clearly, and here a drawing by M. Antoniadi showing all trustworthy details he could see on Mr. Lowell's 1907 photographs. In them there is no trace of the network. Examine next these beautiful photographs, Plate VIII. (not drawings from photographs but direct reproductions of the photographs themselves) taken by Mr. Barnard, in 1909, with the 40-inch Yerkes telescope. These show no geometric network, but much fine detail. Now recall the relative appearance of the drawings and photographs of Jupiter and Saturn shown earlier. The drawings showed far more detail than the photographs, but the general nature of the detail was the same in both. We can hardly expect, therefore, that photographs of Mars* will show as much detail as do the draw-

*See M. Antoniadi's article in *Monthly Notices* R. A. S., Vol. LXXI., p. 714. Photographs of Mars by Barnard and Hale are described (with illustrations) and another argument adduced against the "geometrical network."

ings, but they should show detail of the same kind.

All things considered, I think it is fair to say, that the true nature of the markings is not yet definitely settled, but that the evidence from the last opposition, as a whole, is less favorable to the geometric representation than to the natural or irregular one. If several of the experienced observers who now give us such conflicting views of Mars could observe the planet at this year's opposition with the same telescope and at the same time and place, thus eliminating all the variables except the personal equation, we might be able to decide what the real markings are, and to account for the widely divergent representations of them.

Until we have more definite knowledge on these points it is not worth while to discuss the bearing these surface markings have on our question of life in other worlds. We may note, however, that assuming the fine canals to be real, it does not follow that they indicate the presence of intelligent life on Mars. Mr. Lowell, indeed, argues plausibly in favor of this interpretation, but Professor Arrhenius has recently explained the "canals" as earthquake cracks or fault lines, while Mr. W. H. Pickering's drawings of the crater Eratosthenes show canals on the Moon where it is certain that there are no living beings. As the best conclusion now possible we may say that, while the conditions on Mars do not seem to prohibit the existence there of vegetable or even, perhaps, of animal life, there is not, at present, any evidence that the planet is inhabited by intelligent beings.

The general result of this investigation, then, is that observations with the best instruments available to-day have afforded no certain and undisputed evidence of the existence of intelligent life on any planet except the Earth. The major planets and Mercury are certainly devoid of life of any form; Venus we know nothing about from direct observation, and our inferences must wait upon the definite determination of its rotation time; Mars may have vegetable and animal life, but the general conditions seem adverse to the presence there of intelligent life, and there is no direct evidence in its favor.

PLATE XIX.

GREAT STAR-CLOUD IN SAGITTARIUS

From a photograph by E. E. Barnard, 10-inch Bruce Telescope, Yerkes Observatory, June 29, 1905. Exposure 4h. 53m.

Are we, then, the only intelligent beings in the Universe? The stupendous egotism of such a conclusion would of itself be enough to to bid us pause. But, indeed, we may reasonably argue against it.

The Sun, we know, is merely a star essentially like the other stars in space. Now at the Solar Observatory the other day I saw a photograph of about two square degrees of the sky $= \frac{1}{20000}$ part of the whole spherical surface. On this plate were the images of 100,000 stars! Again, here is one of Barnard's photographs of a portion of the Milky Way. Count, if you can, the stars it shows! Clearly we must number the stars revealed by modern telescopes and cameras by the hundreds of millions. Are these suns the centres of systems like our own? Direct observation will give us no answer, for no telescope yet dreamed of or likely to be constructed, will ever enable us to see a planet outside of the solar system. To see Jupiter from the distance of the nearest fixed star would require a telescope with an object glass 21 feet in diameter. We know that at least $\frac{1}{5}$ of the stars are double stars, systems of two suns, and a man may far more easily serve two masters than a planet, two suns. But this still leaves hundreds of millions of single suns, any of which, as far as we know, may be attended by planets. Let us now repeat the late Professor Newcomb's argument from the mathematical theory of probabilities.

Suppose a heap of one million grains of corn all white except one, which is red. If a man, blindfolded, puts out his hand and takes one grain from the heap, what are the chances that he will pick the red grain, all grains being supposed equally accessible? Just one in a million! Were death the penalty for the choice of the red grain, no sensible man need hesitate to put forth his hand under such conditions. He takes far larger chances of death each day of his life. But march the 1500 millions of mankind past this heap, each, blindfolded, taking up and dropping again one grain, and it is certain that 1500 of them will pick the red grain. The application is obvious.

Grant the possibility of planets attending some of the suns

in space, and make the chances only one in a million that the conditions essential to the origin of life and to its development to the stage of intelligence are happily met together on any planet. We may then point to any star at random and say with practical certainty "No life exists in that system." But with even greater assurance we may affirm that among the hundreds of millions of single suns, are hundreds which are attended by inhabited worlds. This is not mere idle speculation, but a reasonable conclusion, though no improvement in our telescopes may ever permit us to verify it by observation.

PLATE XX.

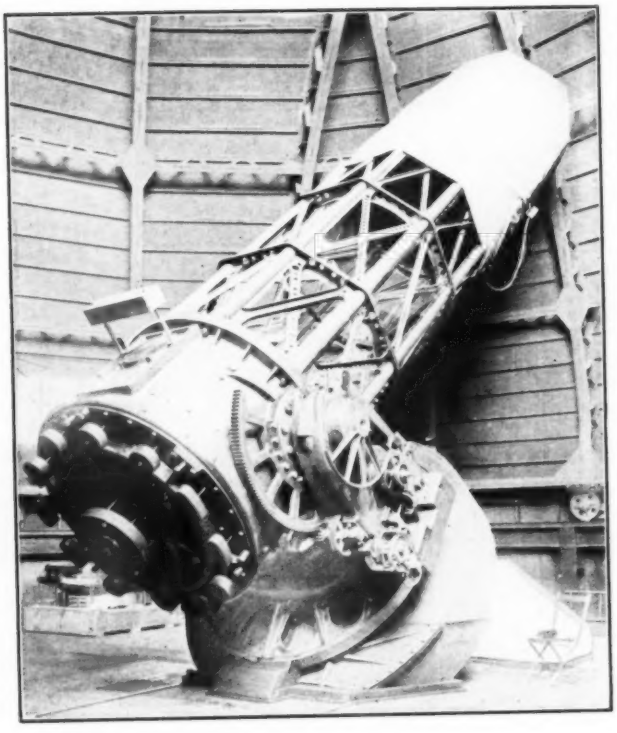


FIGURE 2.

The 60-inch reflecting telescope of the Mt. Wilson Solar Observatory, near Pasadena, Southern California

A GREAT MODERN TELESCOPE*

By C. A. Chant

ONE might be well acquainted with the appearance of the ordinary refracting telescope, which has contributed so much to the world's pleasure and knowledge, and yet hardly be able to recognize the use of some extraordinary constructions, still called telescopes, which have been brought into existence for the investigation of special problems in astronomy. These have arisen through the union of physics with astronomy, and the resulting development of that great branch of science which for some years bore the name of "The New Astronomy," but which is now known as "Astrophysics." The wonderful growth of this subject has been largely due to two great discoveries: (1) the method of spectrum analysis, and (2) the photographic dry-plate.

In the refracting telescope there is a lens, or a combination of lenses, called the objective, at one end of the tube; and at the other end is another combination known as the eye-piece. Light from the heavenly body passes through the objective, which converges the rays to form an image of the object at the principal focus of the lens, and this image is then observed through the eye-piece, which acts like a simple magnifying lens.

Now a concave mirror converges the light which falls upon it, just as a lens does, and so it is possible to construct a telescope, using a mirror for objective. Such a telescope is called a reflector, and the manner in which it works is shown in the accompanying diagram. (Fig. 1.)

The large concave mirror M, which is the most distinctive part of the instrument, is placed at the lower end of the tube. The light from the heavenly body passes down the tube, as

* Reprinted from *The Westminster* for August, 1911.

shown by the arrows, and strikes the mirror, which returns the light, directing it towards *n*, where the image of the body would be formed. For convenience, however, a small plane (*i. e.*, flat)

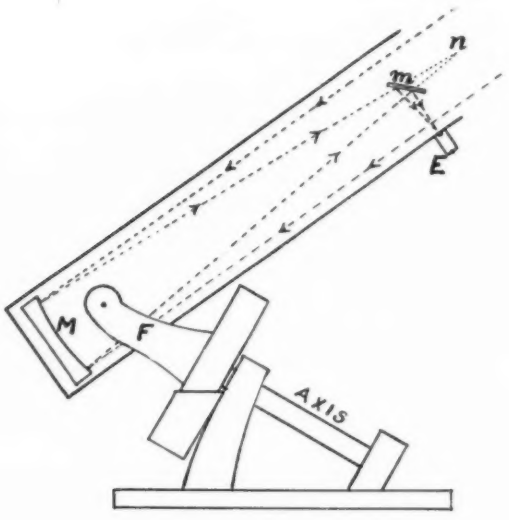


FIGURE 1.

Diagram showing the action of the reflecting telescope. M is the large concave mirror on which the rays strike. They are reflected back to the small plane mirror *m*, and thence into the eye-piece E.

mirror *m*, is interposed in the path of the light and this reflects it out to the eye-piece E, behind which is the observer's eye. In place of the eye-piece one can substitute a photographic plate.

The reflecting telescope is not by any means a new invention. The great Sir Isaac Newton constructed one about 1670; and it was brought into great prominence by Sir William Herschel a hundred years later, who, failing to find any one competent to undertake the grinding of large mirrors, resolutely set about it himself. He reached a stage of perfection never before approached; and using his own telescopes, the greatest of which was 4 feet 10 inches in diameter and 40 feet long, he made

PLATE XXI.

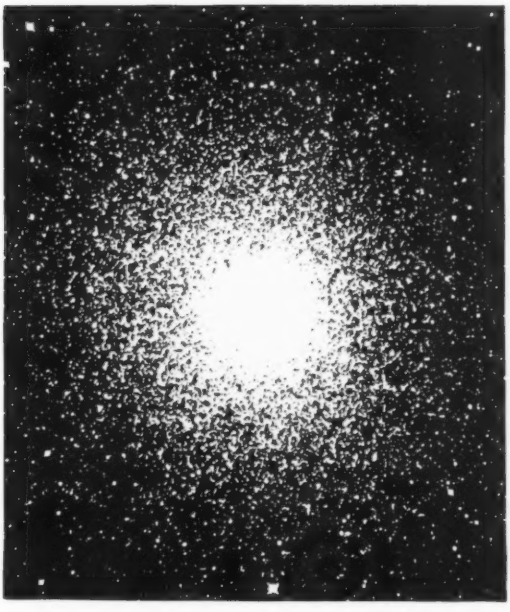


FIGURE 3.

A portion of the great cluster of stars in Hercules. The photograph showed that there are more than 25,000 stars in it. Exposure of negative eleven hours.

a survey of the sky and thus laid the foundation of our knowledge of the structure of the universe. In 1842, Lord Rosse, of Parsonstown, near Dublin, Ireland, built his famous instrument, which had a mirror six feet in diameter and a tube 54 feet long, the whole weighing 15 tons. In these instruments the mirror was made of an alloy of copper and tin, which is hard to work but which keeps its polish well. These giant instruments were very powerful; but they were rather difficult to manage, and the refracting telescope gradually increased in size and distinctly took the lead.

But in recent years it has been demonstrated that for photographing faint objects, such as nebulæ and star-clusters, and for much work with the spectroscope, the reflector is decidedly superior. This has led to the construction of some notable instruments. The most powerful, as well as the most perfect of these, I shall briefly describe.

It belongs to the Carnegie Solar Observatory and is mounted on the summit of Mount Wilson, near Pasadena, in southern California. A view of it is given in the accompanying engraving. (Figure 2.)

The mirror is made from a great disc of glass. It is 60 inches in diameter, 7⅝ inches thick at the edge and hollowed out so as to be ¾ inch thinner at the centre. It weighs 1,900 pounds. The coat of silver is deposited, by a chemical process, upon the front surface, not on the rear as in our ordinary mirrors; but the layer is so thin that it contains no more silver than is in a Canadian 5-cent piece. One would think that a glass disc so thick would not change its shape no matter how it was supported, but such is not the case. It has to be held so that the pressure is uniformly distributed over its rear surface. This is accomplished by an elaborate system of levers and weights, seen in the picture at the lower end of the tube. The slightest bending of the glass alters the curvative of the mirror and rends it of less use than a mirror or lens of much smaller diameter.

It will be seen that the tube in this case is just an open steel framework. The elaborate mechanism at the side is for pointing

the telescope in any desired direction, but the greater part of the controlling mechanism is below the floor and cannot be seen. The telescope is mounted in a fork F (Fig. 1), rigidly attached to the end of an axis parallel to the axis of the earth. This axis is a hollow forging of nickel-steel, 15 feet long and varying in diameter from 15 to 18 inches, and an immense driving-clock with a revolving pendulum causes it to rotate once in 24 hours. This allows the telescope to follow the stars in their motion across the sky. Now the moving parts of the instrument weigh nearly 23 tons, and one would expect that great force would be required to overcome the friction of the bearings. But this friction is almost entirely eliminated by an extremely ingenious arrangement. Upon the axis is a great hollow disc of steel, ten feet in diameter and two feet thick. The upper portion of it is seen in the picture. This disc snugly fits in a trough into which mercury is poured, As a cork is buoyed up by water, so this disc is held up by the mercury, and almost all of the pressure is removed from the bearings. As a result, the clock moves the great mass with ease and wonderful smoothness.

Now the mirror is figured with the utmost accuracy, and a change in temperature alters its form. A rise in temperature also causes expansion in the mountings. Indeed, experiments showed that for highest efficiency there should not be a daily variation in the temperature of the mirror of more than two degrees Fahrenheit. To accomplish this result extraordinary precautions have been taken. The building containing the instrument has two sheet-metal walls, with a space of two feet between them. The dome is further protected from the sun by a white canvas shield two or three feet above it. The whole building is practically air-tight. Still further, during the day the telescope is covered by a "canopy" 15 feet high, 15 feet long and 11 feet wide, made of four thicknesses of fine woollen blankets, quilted between covers of white canvas.

With these precautions, and numerous other refinements which I cannot specify here, results have been attained with this instrument which are far in advance of any heretofore secured.

PLATE XXII.

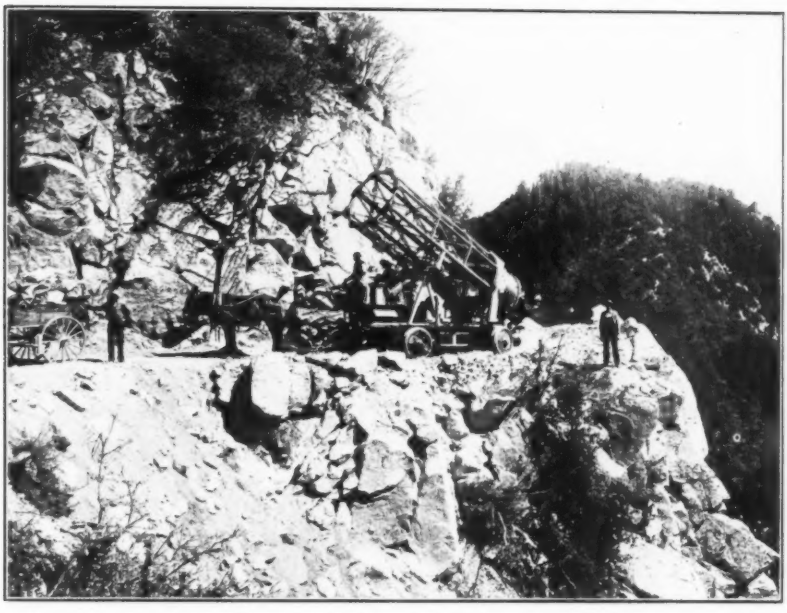


FIGURE 4.

The tube of the great telescope on its way up the steep and narrow mountain road

During the summer of 1910 the present writer had the privilege of observing the Great Cluster of Stars in the constellation Hercules, the planet Saturn and the "Trapezium" in the Orion Nebula. The revelation of detail and of delicate coloring was simply exquisite.

But the photographs of celestial objects obtained with the instrument are even more notable. They exhibit the structure of some of the faint nebulæ and clusters in a manner never before approached. The accompanying picture (Fig. 3) is made from a photograph of a portion of the great Hercules Cluster. This immense aggregation of suns was discovered in 1714 by Halley. In a small telescope it appears as a hazy star, but a large instrument reveals a mass of sparkling points of light. At first it was thought that there might be one or two thousand separate bodies in it, and later this was increased, by actual count of an excellent photograph, to 6,000; but the photographs with the 60-inch reflector reveal as many as 25,000 single stars, all probably connected as a whole and each a sun! Star-clusters are, perhaps, the most difficult of astronomical subjects to photograph. To secure the picture shown, the photographic plate had to be exposed eleven hours, the exposure having been made on three successive nights.

The 60-inch reflector was constructed at Pasadena, in the instrument shop of the Solar Observatory. In design and construction it is entirely the product of Professor G. W. Ritchey, though in carrying out his plans he had the assistance of several very skilful helpers. Professor Ritchey has also been the chief observer with his telescope, and the negatives he has obtained are simply unrivalled.

To reach its destination on Mount Wilson, the telescope had to be carried up a steep and narrow road, ten miles in length, cut from the side of the mountain. An accompanying picture (Figure 4) shows the tube on its way up. It is on a truck of special construction, propelled both by gasoline motors and mules. The length of the tube demanded that it should be movable on its truck, in order to escape overhanging rocks.

The great success obtained with the 60-inch instrument led Mr. John D. Hooker, a public-spirited citizen of Los Angeles (10 miles from Pasadena), to contribute $50,000 towards the construction of a 100-inch reflector, and this work was placed in Professor Ritchey's hands. Great difficulty has been experienced in obtaining a disc of glass large enough for the purpose. In our last illustration (Figure 5) is shown one which was received from France, a foot thick and weighing 4½ tons. On being received its two surfaces were ground flat and parallel, and it was made circular. In the picture this latter operation is shown in progress; the great disc is resting on the grinding table and is being made to rotate while the edge is ground. But the disc was made up of three distinct layers, obtained by pouring three separate meltings one upon the other, and it was feared that it would not be rigid enough to withstand change of figure, and so it was discarded.

A subsequent attempt to cast another disc and to anneal it — indeed it is in the annealing that all the difficulty lies — was unsuccessful; and the makers have practically abandoned the project of supplying a single disc of the required thickness.*

In this predicament Professor Ritchey has been driven to a new expedient. He proposes to build up a disc, by taking discs 100 inches in diameter and two inches thick (which can be obtained quite readily), grinding their surfaces perfectly flat, and then placing one above the other with strips of uniform thickness between them, all cemented together into a whole. Satisfactory mirrors 24 inches in diameter have been made on this plan, and experiments are under way with larger ones, in order to test thoroughly the method before undertaking the monster 100-inch one. So far everything appears promising and it is to be hoped that this invention, truly the child of necessity, will prove entirely successful, so that in a few years the world may be put in possession of a still grander triumph of Professor Ritchey's ingenuity and skill.

*Late information states that an attempt to use the original disc will be made.—C. A. C.

PLATE XXIII.

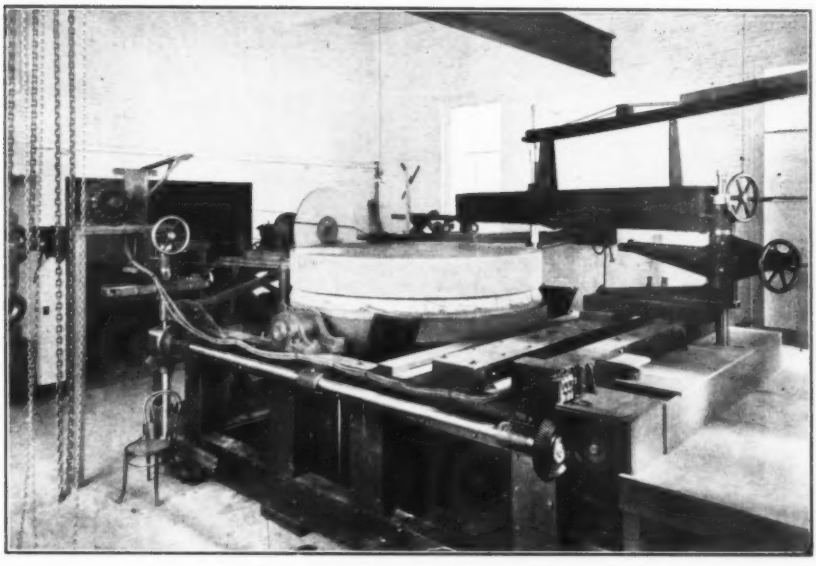


FIGURE 5.

A glass disc 100 inches in diameter and 12 inches thick, on the machine for grinding it into a concave mirror

THE ORBITS OF THE SPECTROSCOPIC COMPONENTS OF *d* BOOTIS

By W. E. Harper

THIS star, $\alpha = 14^h\ 05^{m}\cdot8$, $\delta = +\ 25^{\circ}\ 34'$, photographic magnitude 5·3, was announced as a spectroscopic binary by Campbell and Wright in 1900. Approximate measures of the four plates secured showed a range of 75 km. Their measures referred solely to one component; they made no mention of the spectrum of the other component being visible, though, no doubt, such is the case on two of their plates.

Fifty-three spectrograms of the star have been obtained at this observatory during the years 1907, 1910 and the present year, and these form the basis of the present discussion of the orbit. The first four were made with the Universal spectroscope as adapted for radial velocity work, linear dispersion at $H\gamma$ 18·6 tenth-metres per millimetre, the next one with three-prism dispersion of 20·2 tenth-metres per millimetre at the same region, and the remainder of the plates with the new single prism instrument, dispersion at same region of 33·4 tenth-metres per millimetre. For number 3368 a Sigma plate was used; all the other plates were of Seed 27 Emulsion.

As intimated above both spectra are visible, (Plate XXVI.*) are quite similar and of type F 5. For considerably over half the period the spectra are well resolved and measures were made on the lines of each component. At first all the lines that were at all measurable were used; gradually those were eliminated which from their complicated nature could not be depended upon.

* NOTE.—Owing to the fact that the enlargement was made by moving the negative up and down, a few spurious lines are introduced.

The final outcome was a selection of thirteen lines, given in the table below, upon which all the measures were based. When all the measures were completed a table of residuals of each line, from the mean given by the plate as a whole, was formed and new wave-lengths were derived so that the sum of the residuals equalled zero for each line. The first column gives the wave-length as assumed at the start, the second the number of times measured, the third the average residual and the last the wave-length as corrected for this star. Outside of *H*, it will be noticed that practically all the lines selected were those due to iron or blends of iron.

LINES USED IN *d* BOOTIS

λ	Times Measured	Average Residual	Corrected λ
4549·766	34	− 0·0 km.	4549·766
4415·293	41	− 3·4	4415·343
4340·634	31	− 1·8	4340·660
4325·829	43	+ 1·2	4325·812
4308·081	54	+ 2·7	4308·042
4271·760	53	− 0·9	4271·773
4260·540	56	+ 3·2	4260·405
4143·928	49	− 0·7	4143·938
4071·901	26	− 2·9	4071·940
4063·756	38	− 2·9	4063·795
4045·975	52	− 0·2	4045·978
4005·430	47	+ 5·1	4005·362

With the exception of the last line, whose wave-length was very uncertain at the commencement of the measures, none of the wave-lengths as assumed are in very great need of correction. An unpublished investigation by the writer of the effect on the elements of an orbit of the use of wave-lengths which, treated similarly, gave residuals somewhat as those above, shows that the changes are almost inappreciable. However, as the last line needed correction it was decided to use the corrected wave-lengths throughout and the measured velocities were revised accordingly.

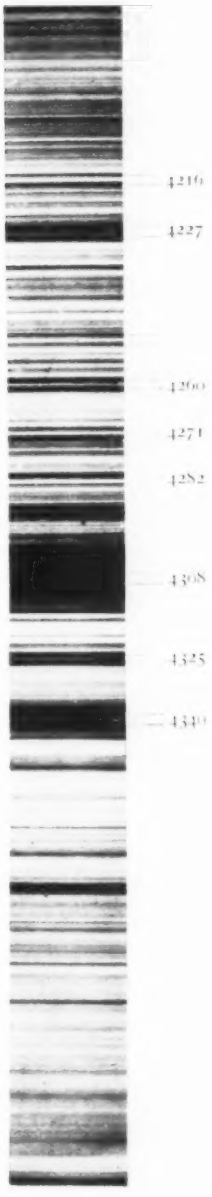
In the table following is given a summary of the measures. The phases are reckoned from the periastron passage finally

accepted, J. D. 2417679·523, using the period 9·6045 days. The maximum weight assigned a plate was 10, depending for the most part on the sum of the weights given the separate lines when the measurement was being made. The residuals given are scaled from the final curve. These appear only for those plates where the spectrum lines of the components were resolved. The other velocities are derived from measures on blends and are subject to considerable error. For some distance on either side of the intersection of the curves with the γ-line where the lines are more or less overlapping the tendency is for the measured velocities to deviate from their true position towards the γ-line and such observations can only be made use of to advantage when grouped over a large phase interval, the extent of the interval on each side of the crossing point being approximately the same.

Measures of *d* Bootis

Plate No.	Julian Day	Phase	Component I.			Component II.		
			Velocity	Wt.	O-C	Velocity	Wt.	O-C
699	2417671·769	1·851	+ 85·0	10	+ 6·0	- 59·9	9	+ 2·8
776	719·635	1·694	+ 71·3	2	- 7·5	- 71·5	2	8·7
778	720·593	2·052	+ 81·5	4	+ 12·0	- 54·7	3	2·2
798	7727·653	·108	+ 17·8	6				
3368	8759·854	4·627	+ 17·1	5				
3466	820·768	4·310	+ 7·6	7				
3475	832·702	·039	+ 35·7	5				
3512	859·591	8·319	- 54·2	10	- 4·5	+ 73·1	6	+ 0·7
3518	864·584	3·708	+ 26·9	10				
3524	866·581	5·705	+ 0·6	9				
3550	881·586	1·501	+ 73·4	9	- 3·9	- 61·2	9	0·0
3577	903·550	4·256	+ 10·3	7				
3594	913·542	4·643	+ 13·5	6				
3609	916·556	7·057	- 64·8	4	- 5·2	+ 69·3	3	- 11·7
3624	8923·534	5·031	+ 3·5	3				
3896	9027·967	3·814	+ 28·4	6				
3926	046·875	3·513	+ 26·9	2				
3945	053·958	·992	+ 60·0	8	0·0	- 56·6	5	7·0
3954	054·925	1·959	+ 83·2	9	+ 4·5	- 56·5	7	+ 5·8
3979	057·890	5·319	+ 8·7	4				
4044	098·881	7·497	+ 57·0	3	- 0·2	+ 78·4	2	2·4
4052	099·890	8·506	- 46·6	7	- 1·8	+ 69·5	5	+ 2·5
4064	102·846	1·857	+ 77·7	5	- 1·0	- 62·8	5	+ 4·0
4074	103·833	2·844	+ 64·8	7	- 0·4	- 60·7	5	- 12·4
4126	112·892	2·299	+ 79·6	8	+ 3·8	- 59·3	6	0·0
4142	120·824	·626	+ 40·3	3	- 1·7	- 39·6	2	+ 2·4
4159	129·844	·042	+ 10·3	9				
4172	134·860	5·058	+ 8·4	10				
4183	137·853	8·051	- 55·1	3	+ 0·2	+ 75·0	3	3·5
4190	138·712	8·910	- 29·6	4	- 2·0	+ 57·2	2	+ 8·2
4208	145·807	6·400	- 40·5	5	+ 0·2	+ 66·9	4	+ 4·1
4218	146·816	7·409	- 52·2	7	+ 5·0	+ 74·1	4	- 6·0
4233	148·801	9·394	+ 6·4	7				
4239	149·708	·697	+ 49·8	5	- 4·2	- 35·4	2	+ 1·2
4252	151·784	2·773	+ 66·6	7	- 0·2	- 50·6	4	- 0·9
4260	152·781	3·770	+ 22·0	4				
4278	155·812	6·801	- 45·3	4	+ 3·5	+ 78·0	2	+ 6·2
4304	173·687	5·407	- 1·0	6				
4312	176·740	8·520	- 40·9	4	+ 3·4	+ 71·6	2	+ 4·8
4315	178·760	·935	+ 71·3	7	+ 7·8	- 47·8	5	0·8
4328	183·716	5·891	- 17·4	2				
4338	187·705	·275	+ 11·9	5				
4344	189·666	2·236	+ 73·6	5	2·7	- 60·8	4	0·8
4357	196·026	9·196	- 0·7	7				
4382	211·606	4·968	+ 13·2	9				
4390	215·046	8·008	- 34·8	2				
4391	216·502	·340	+ 0·9	2				
4405	221·586	5·343	+ 12·4	7				
4411	222·674	6·431	- 37·0	2	+ 4·4	+ 57·5	1	- 5·8
4420	225·559	9·313	+ 6·4	8				
4425	231·003	5·756	+ 5·0	6				
4431	232·579	6·732	- 34·7	8	+ 12·9	+ 83·8	3	+ 13·3
4440	238·632	3·180	+ 54·6	3	- 2·2	- 39·9	3	0·4

PLATE XXIV.



SPECTRUM OF β BOÖTES, SHOWING DOUBLE LINES

Photographed 1907, April 5. Length 11 times, width 60 times the original.

For convenience of reference, the early observations of the Lick Observatory are here appended.

LICK OBSERVATIONS

Date	Julian Date	Velocity	Residual from Curve
1900 March 27	2415106·881	+ 79	+ 3·0
April 4	114·953	+ 3	− 0·3
" 9	119·905	+ 11	− 1·7
" 17	127·814	+ 60 ±	+ 0·6
1902 May 27*	897·715	+ 11	− 1·2

* Unpublished, but communicated through kindness of the Acting Director.

The period deduced from our own observations and the published ones of Lick, assuming their observations on the meridian, was 9·605 days. This was the period used throughout. A correction of − 0·0005 days was made to this when the G. M. T. of the Lick plates was received. With the exception of the first four all our observations are practically of one year, so that the small correction to the period will not affect the results. Likewise three out of the four 1907 plates are at the crests of the curve and no appreciable change will result from the use of the revised period. The correction, however, will accumulate to approximately 0·070 days in the interval over which our observations extend and accordingly a correction of + 0·070 days was added to the derived value of T making it 2417679·523 as given in final elements.

The observations on component I. were first grouped according to phase into thirteen normal places. The peculiar deviation effect near the intersection of the curve with the γ-line, previously referred to, was in evidence in four or five normal places, abnormal residuals for these groups being the rule.

Preliminary elements by the graphical method were obtained, which outside of the groups mentioned, satisfied the observations quite well. They were the following:

Preliminary elements for solution of component I.

P = 9·605 days
e = ·15
ω = 280°
K = 68· km.
γ = + 9·23 km.
T = J.D. 2417679·600

It could be seen that in a least-squares solution the large residuals, alternately above and below the curve on each side of the crossing points, would play the most important part and would cause considerable changes in the elements; nevertheless, as a matter of interest merely to see the extent of such changes, a solution was made. The period was considered determined and corrections were obtained for the other elements as follows:

$$\delta\gamma = + 2{\cdot}54 \text{ km.}$$
$$\delta K' = - 2{\cdot}48 \text{ km.}$$
$$\delta e = + {\cdot}090$$
$$\delta\omega = - 13^\circ\ 11'$$
$$\delta T = - {\cdot}235 \text{ days,}$$

so that the first corrected set of elements for component I. are:

$$P = 9{\cdot}605 \text{ days}$$
$$e = {\cdot}240$$
$$\omega = 266^\circ\ 49'$$
$$K' = 65{\cdot}52 \text{ km.}$$
$$\gamma = + 11{\cdot}77 \text{ km.}$$
$$T = \text{J. D. } 2417679{\cdot}365.$$

If we compare these with the values finally accepted we notice differences of considerable magnitude. The eccentricity is here considerable increased. Another marked effect is the lowering of both positive and negative maxima from that given by the final elements which latter maxima seem well substantiated by the observations at a time when the observed velocities can be relied on.

Though a second solution according to the foregoing grouping should have been carried out to satisfy the agreement between equation and ephemeris residual, yet any changes thereby deduced would have been of a vanishing order, and as the grouping at basis was faulty, no good purpose could have been served by such solution. In the new grouping which was now made all the plates whereon the component spectra were not distinctly resolved were grouped into two normal places at or near the two

points of intersection of the curves. They have, owing to the number of plates involved, relatively high weights.

The same set of preliminary elements as before were used and the following corrections resulted.

$$\delta\gamma = + 2{\cdot}38 \text{ km.}$$
$$\delta K' = - {\cdot}16 \text{ km.}$$
$$\delta e = + {\cdot}030$$
$$\delta\omega = - 12^\circ\ 01'$$
$$\delta T = - {\cdot}206 \text{ days.}$$

The corrected elements for component I. then are:

$$P = 9{\cdot}605 \text{ days}$$
$$e = {\cdot}180$$
$$\omega = 267^\circ\ 59'$$
$$K' = 68{\cdot}16 \text{ km.}$$
$$\gamma = + 11{\cdot}61 \text{ km.}$$
$$T = \text{J. D. } 2417679{\cdot}394.$$

The sum of the squares of the residuals was reduced from 883·5 to 147·1.

Elements corresponding almost to the above corrected values were used as preliminary in a least-squares solution for component II. The maximum positive for the curve seemed to be fixed about + 79 by the observations, while the maximum negative was - 61. This with corresponding values for e and ω gave a somewhat discrepant value for γ, nevertheless the elements following were assumed as preliminary for the solution.

$P = 9{\cdot}605$	Preliminary elements for solution of component II.
$e = {\cdot}180$	
$\omega = 88^\circ$	
$K' = 70$ km.	
$\gamma = + 8{\cdot}56$ km.	
$T =$ J.D. 2417679.394	

The two normal places for component I. previously referred to as comprising all the plates on which the lines were blended were also used in this solution. This seemed a reasonable procedure as the blended observations refer equally to both com-

ponents. The following corrections were the result of this solution.

$$\delta\gamma = + 1{\cdot}07 \text{ km.}$$
$$\delta K' = + 2{\cdot}29 \text{ km.}$$
$$\delta e = - {\cdot}025$$
$$\delta\omega = + 2^\circ\ 10'$$
$$\delta T = - {\cdot}031 \text{ days}$$

so that the corrected value for component II. are :

$$P = 9{\cdot}605 \text{ days}$$
$$e = {\cdot}155$$
$$\omega = 90^\circ\ 10'$$
$$K' = 72{\cdot}29 \text{ km.}$$
$$\gamma = + 9{\cdot}63 \text{ km.}$$
$$T = \text{J. D. } 2417679{\cdot}363.$$

These values reduced Σpvv from 490·8 to 143·0.

The question now arises as to the best method of combining the results arrived at from each component to secure uniform values for the elements. For the values of γ, e and T must be identical, whilst the values for ω must differ by 180°. As we have determined them, they are :

	Component I.	Component II.
γ	+ 11·61 km.	+ 9·63 km.
e	·180	·155
ω	267° 59′	(270° 10′ − 180°)
T	J. D. 2417679·394	J. D. 2417679·363

One might combine them according to the relative weights of the observations, which in this case are 31·3 and 25·5 for components I. and II. respectively. Again one might combine according to the probable errors of the determined quantities, weighting as the inverse square of the probable errors. Both these have been performed but before giving the results a better method than either, suggested by the Director, Dr. W. F. King, will be given. It consists in combining all observations on both components into *one* set of observation equations from which, of course, only *one* set of elements result. In building up the obser-

vation equations one must be careful to remember that for ω in one case we must use $180 + \omega$ in the other.

For preliminary elements the following were assumed.

P = 9·605 days	Preliminary elements for combined solution
e = ·180	
ω = 268° and 88°	
γ = + 8·56 km.	
K_1 = 67·87 km.	
K_2 = 70· km.	
T = J. D. 2417679·394	

This solution gave the following corrections:

$$\delta\ \gamma = + 1{\cdot}25 \text{ km.}$$
$$\delta\ K_1 = + {\cdot}53 \text{ km.}$$
$$\delta\ K_2 = + 2{\cdot}05 \text{ km.}$$
$$\delta\ e = - {\cdot}011$$
$$\delta\ \omega = + 5^\circ\ 00'$$
$$\delta\ T = + {\cdot}059 \text{ days}$$

Hence the final values which are considered as definitive, with their probable errors, are the following:

P = 9·6045 days	Final Values
e = ·169 ± ·011	
ω_1 = 273° ± 2° 55′	
ω_2 = 93° ± 2° 55′	
K_1 = 68·40 km. ± 0·92 km.	
K_2 = 72·05 km. ± 1·15 km.	
A_1 = 69·00 km.	
B_1 = 67·80 km.	
A_2 = 71·41 km.	
B_2 = 72·69 km.	
T = J. D. 2417679·523 ± ·073	
γ = + 9·80 km. ± 0·56 km.	
$a_1 \sin i$ = 8,904,000 km.	
$a_2 \sin i$ = 9,380,000 km.	
$m_1 \sin^3 i$ = 1·36 $\odot$.	
$m_2 \sin^3 i$ = 1·29 $\odot$.	

The value of Σpvv for the normal equations was reduced from 786·5 in the case of the preliminary elements to 429·8 and as may be noted in the following table, last column, satisfactory agreement was obtained between equation and ephemeris residuals. The phases in the table are referred to the final value for T.

NORMAL PLACES, COMBINED SOLUTION

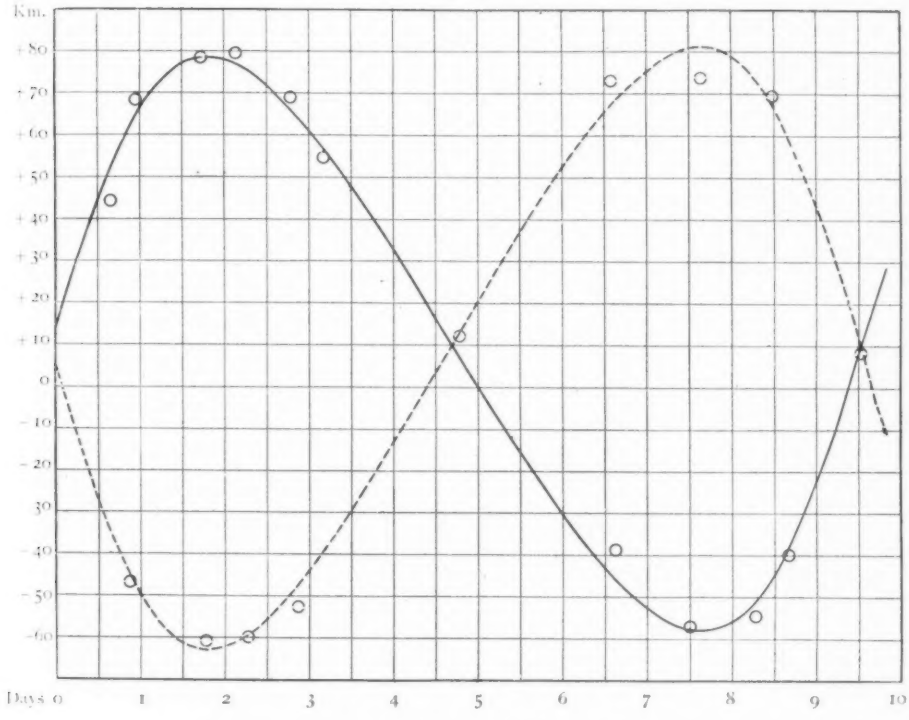
	Mean Phase	Mean Vel.	Weight	O – C	Equation-Ephemeris
1	1·737	+ 78·53	2·5	– ·18	+ ·06
2	2·141	+ 79·71	2.	+ 2·59	+ ·09
3	2·785	+ 69·21	2·	+ 2·70	+ ·22
4	3·169	+ 54·60	·3	– 2·42	+ ·16
5	6·619	– 38·70	2·	+ 6·67	– ·08
6	7·497	– 56·96	1·5	+ ·73	– ·08
7	8·263	– 54·41	1·5	– 3·17	– ·12
8	8·657	– 39·87	2·	– 1·17	– ·14
9	·653	+ 44·26	1·5	– 7·65	– ·09
10	·955	+ 68·47	1·5	+ 4·00	+ ·05
11	1·780	– 60·70	3·5	+ 2·18	– ·02
12	2·268	– 59·90	1·	– ·29	– ·05
13	2·862	– 62·65	1·5	– 4·62	– ·13
14	4·782	+ 12·08	10·	– ·14	– ·07
15	6·575	+ 73·25	1·	+ 6·35	+ ·04
16	7·043	+ 73·83	1·	– 7·38	+ ·23
17	8·487	+ 69·60	1·5	+ 2·08	– ·29
18	9·526	+ 8·41	4·5	– 2·28	+ ·13
19	·872	– 46·72	1·5	– 2·06	+ ·11

The probable error of a plate obtained from the residuals as scaled, with their corresponding weights, is ± 3·21 km. per sec. In the curves shown, which represent the final elements, the continuous curve and circles refer to component I. and the broken ones to component II.

A comparison of the elements common to both components, arrived at in the various ways, is given in the following table.

COMPARISON OF ELEMENTS

Elements	Solution Component I	Solution Component II	Combined According to Weights	Combined According to Probable Errors	One Direct Solution
γ	+ 11·61 km.	+ 9·63 km.	+ 10·72 km.	+ 10·80 km.	+ 9·80 km.
e	·180	·155	·169	·170	·169
ω	267° 59′	90° 10′	268° 58′	269° 11′	273° and 93°
T	..... 9·394	..... 9·363	..... 9·380	..... 9·377	..... 9·453



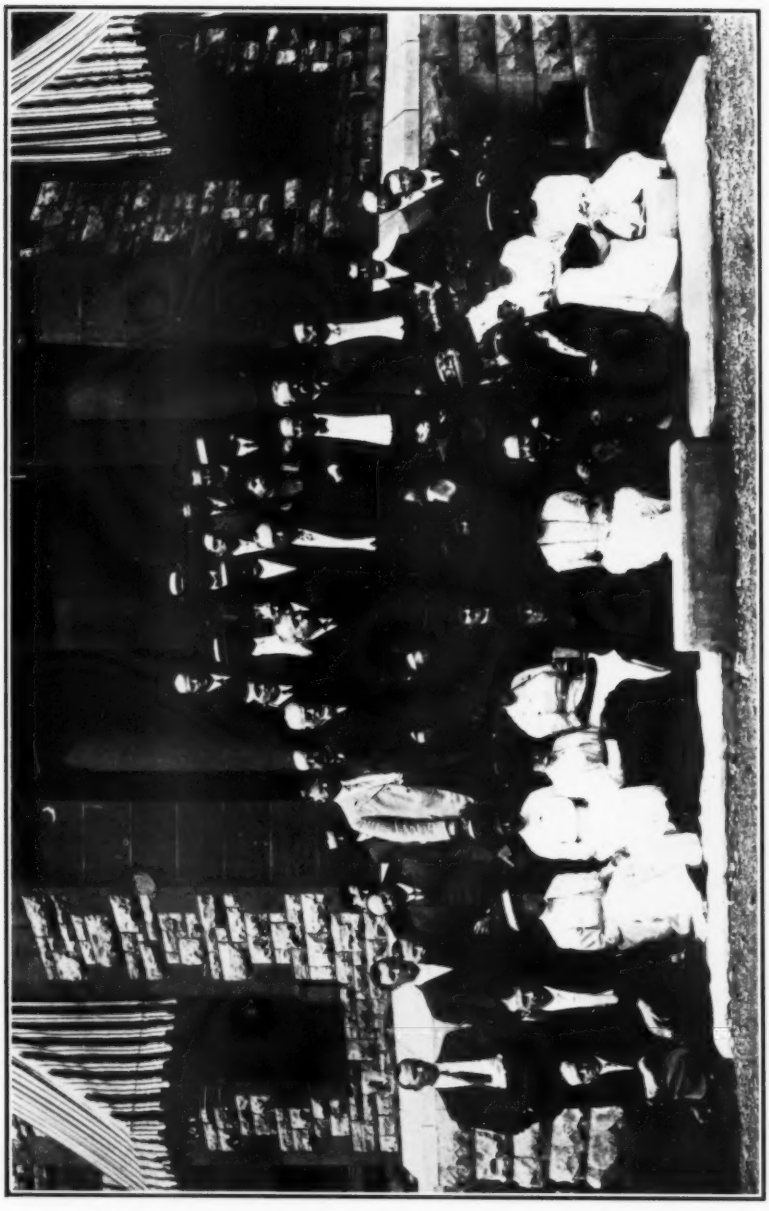
VELOCITY CURVE OF *d* BOÖTIS

There seems no doubt to the writer that the last solution wherein all the observations on both components are grouped into one set of observation equations resulting in a uniform set of values, is the only rigid one, and, as previously stated, the suggestion for such a procedure came from the Director, Dr. W. F. King, to whom my acknowledgements are due for this and other valuable suggestions.

One detail in which, for future work, the foregoing can be improved upon. The two groupings representing the blend

plates should be broken up into four, with residuals scaled from each curve, the total weight assigned the four normal places being equal to that formerly given the two; or, retaining the two normal places, adjust the corresponding residuals in the observation equations so that they represent the deviations from both curves instead of from one alone as in the present discussion.

DOMINION OBSERVATORY,
OTTAWA, CANADA,
August, 1911.



TWELFTH MEETING OF THE ASTRONOMICAL AND ASTROPHYSICAL SOCIETY OF AMERICA, OTTAWA,
August 23-25, 1911.

R ssell, Stebb ns, Curt ss

THE AUDITING COMMITTEE AT WORK

President Picker'ng, Miss Cannon, M ss Furness

Chief Astronomer King

THE ASTRONOMICAL AND ASTROPHYSICAL SOCIETY OF AMERICA

OTTAWA MEETING

By C. A. Chant

THE twelfth annual meeting of the above named Society was held at the Dominion Observatory, Ottawa, August 23-25. This was the first occasion on which a meeting of the Society was held outside the United States, and it is a pleasure to be able to state that both from a scientific and from a social point of view it was a decided success.

The programme for the meeting was as follows:—

Wednesday, August 23—

Papers, 10 a.m. to 1 p.m.
Luncheon, 1 to 2 p.m. at the Observatory.
Papers, 2 to 4 p.m.
Reception and Inspection of the Observatory, 4 to 6 p.m.

Thursday, August 24—

Excursion to Gatineau Region:
Leaving Union Station, 9 a.m.
Papers and Nomination of Officers 1.30 to 3.30 p.m.
Returning, arrive at Union Station, 6 p.m.

Friday, August 25—

Papers and Election of Officers, 10 a.m. to 1 p.m
Luncheon, 1 to 2 p.m. at the Observatory.
Papers, 2 to 4 p.m.
Drive to points of interest around the City, 4 to 6.30 p.m.

The Observatory was tastefully decorated with flowers and with Canadian and United States flags, and the grounds were greatly admired. Among the principal matters of interest were the following:—equatorial instrument, (15 inches aperture);

spectrographs, stellar camera, meridian circle, (6 inches aperture, 36 inches circle) ; cœlostat and solar spectrograph, apparatus for distribution of time, measuring machines, seismograph, recording anemometer, thermographs, micro-barograph, library.

The programme was closely followed. On Wednesday and Friday luncheon was served in the Testing Laboratory and was very enjoyable. It afforded an excellent occasion for renewing old friendships and making new ones. The excursion on Thursday by rail to Wakefield, in the Gatineau Valley was a great success. The weather was very agreeable and the luncheon on the high bluff over-looking the village, as well as the session of the Society in the pine grove on the bank of the river will be long remembered.

The following signed the register during the meeting :—

Edward C. Pickering, Harvard College Observatory, Cambridge, Mass.
W. F. King, Dominion Observatory, Ottawa, Ont.
J. S. Plaskett, Dominion Observatory, Ottawa, Ont.
Frank C. Jordan, Allegheny Observatory, Pittsburg, Pa.
Mrs. F. C. Jordan, Pittsburg, Pa.
J. H. Jordan, Marietta, Ohio.
Joel Stebbins, University of Illinois, Urbana, Ill.
Wm. Bruce, Hamilton, Ont.
Rev. D. B. Marsh, Springville, Ont.
John Tatlock, New York City, N.Y.
A. Thos. G. Apple, Lancaster, Pa.
Frank B. Littell, U. S. Naval Observatory, Washington, D.C.
S. I. Bailey, Harvard College Observatory, Cambridge, Mass.
Frank Schlesinger, Allegheny Observatory, Pittsburg, Pa.
S. A. Mitchell, Columbia University, New York City.
George H. Peters, U. S. Naval Observatory, Washington, D.C.
W. E. Harper, Dominion Observatory, Ottawa, Ont.
W. S. Eichelberger, U. S. Naval Observatory, Washington, D.C.
A. B. Turner, College of City of New York, N.Y.
C. A. Chant, University of Toronto, Toronto, Ont.
Henry Norris Russell, Princeton University, Princeton, N.J.
Sarah F. Whiting, Wellesley College, Wellesley, Mass.
Harriet W. Bigelow, Smith College, Northampton, Mass.
Frederick Slocum, Yerkes Observatory, Williams Bay, Wis.
Mrs. Frederick Slocum, Williams Bay, Wis.

Margaretta Palmer, New Haven, Conn.
[Mrs.] Delia D. Pickering, Cambridge, Mass
Anna Clarke, Boston, Mass.
A. E. Douglass, University of Arizona, Tucson, Arizona.
Annie J. Cannon, Harvard College Observatory, Cambridge, Mass.
Edgar Frisby, Washington, D.C.
[Mrs.] L. V. Frisby, Washington, D.C.
Florence E. Frisby, Washington, D.C.
R. H. Curtiss, Detroit Observatory, Ann Arbor, Mich.
C. L. Doolittle, University of Pennsylvania, Upper Darby, Pa.
R. H. Tucker, Lick Observatory, Mt. Hamilton, Cal.
Mrs. R. H. Tucker, Wiscasset, Maine.
Caroline E. Furness, Vassar College, Poughkeepsie, N.Y.
Helen M. Swartz, South Norwalk, Conn.
Beatrice A. Farall, Batavia, N.Y.
Jeanette M. Schoolcraft, Schenectady, N.Y.
R. M. Motherwell, Dominion Observatory, Ottawa, Ont.
R. J. McDiarmid, Dominion Observatory, Ottawa, Ont.
John A. Miller, Swarthmore College, Swarthmore, Pa.
E. S. Manson, Jr., Ohio State University, Columbus, Ohio.
[Mrs.] Millie E. Manson, Columbus, Ohio.
Georgia S. Barber, New Haven, Conn.
R. M. Stewart, Dominion Observatory, Ottawa, Ont.

The election of officers for next year took place on Friday, and resulted as follows: —

President, E. C. Pickering, Cambridge, Mass.
1st Vice-President, E. B. Frost, Williams Bay, Wis.
2nd Vice-President, W. W. Campbell, Mt. Hamilton, Cal.
Secretary, W. J. Hussey, Ann Arbor, Mich.
Treasurer, C. L. Doolittle, Upper Darby, Pa.
Councillors, J. S. Plaskett, Ottawa, Ont., and W. S. Eichelberger, Washington, D.C.

The President of the Society, Professor E. C. Pickering, occupied the chair throughout the meeting. Excepting Thursday, the sessions were held in the lecture room of the Observatory.

In opening the meeting the President gave an analysis of the membership of the Society. Out of a total of 248, there are resident in Massachusetts 68.

Dr. W. F. King, the Chief Astronomer and Director of the Observatory, read a letter from the Deputy Minister of the Interior welcoming to Ottawa, on behalf of the Minister and of the Government, the members of the Society. On behalf of himself and his staff, Dr. King also extended a hearty welcome; and he drew attention to the fact that in the Dominion Observatory there was a case where the Government supported pure science.

The Deputy Master of the Mint extended an invitation to the members to visit that institution, which some took advantage of on Saturday morning.

A letter was read from Professor W. W. Campbell, written in a hospital in Munich where he had been taken on account of an attack of typhoid fever. Dr. Campbell is chairman of the Society's Committee on Co-operation in the Measurement of Stellar Radial Velocities, and he wrote to state his regret that he had been unable to prepare the final report of the committee. A letter was sent to Dr. Campbell, signed by all the members present, expressing sympathy for him in his illness, and the hope for a rapid recovery.

The following papers were presented to the Society :—

1. E. C. Pickering. "A Method of Determining by Photography the First Point of Aries."

In the method proposed trails of stars for a few minutes were obtained at night : the exposure was then stopped, and at noon next day the same plate was exposed to the sun, the interval which had elapsed being obtained from a Riefler clock. A photograph taken in this way was shown (See No. 29, below).

2. Miss Annie J. Cannon. "The Spectra of 762 Double Stars."

This was a report on the spectra, as revealed in the Harvard Photographs, of all the double stars of magnitude 7·5 or brighter contained in Burnham's *General Catalogue* and in Innes' *Reference Catalogue of Southern Double Stars*.

3. Miss Annie J. Cannon. "Classification of Some

Stellar Spectra Photographed with the Slit Spectroscope at the Allegheny, Lick and Yerkes Observatories, Compared with those taken at Harvard with the Objective Prism."

The Draper Catalogue is based wholly on photographs taken with the objective prism, and in order to compare these with results obtained with slit spectroscopes, 131 spectrograms were used. No reason was found for altering the classification as given in the *Catalogue*.

4. J. A. PARKHURST. "The Spectra and Colors of Red Stars of the Classes N and R of the Harvard College Observatory."

5. W. E. HARPER. "The Orbits of the Spectroscopic Components of *d* Bootis."

For this paper, see this issue, page 315.

6. JOEL STEBBINS. "Studies of Bright Variable Stars."

In this paper Professor Stebbins gave an account of further work with the selenium photometer. He was able to apply it to α Orionis, range 0·2 magnitude; and to the eclipsing variables, δ Orionis, range 0·11 magnitude, period 5·3 days (about), and β Aurigæ, range 0·1 magnitude, period 4·95 days.

7. E. S. KING. "The Variability of Polaris."

The variability of Polaris having been announced by Hertzsprung, material in Volume LIX. of the Harvard *Annals* was used to obtain any evidence thereupon. The spectroscopic period of 3·9683 days was accepted, and the light-curves obtained from three independent series of observations confirmed the discovery. Polaris has been used very extensively at Harvard as a photometric standard, but corrections have been made at the time for any possible variation in its magnitude, and so none of the results obtained need be altered.

Professor Stebbins, who read the paper, stated that his results did not agree with those obtained by Mr. King.

8. HENRY NORRIS RUSSELL. "A Study of Visual Binary Stars."

9. FRANK B. LITTELL. "The 6-inch Transit Circle of the United States Naval Observatory."

10. FRANK B. LITTELL. "The Alt-azimuth Instrument of the United States Naval Observatory."

Papers 9 and 10 embodied the results of an exhaustive study of these two great instruments.

11. W. J. HUMPHREYS. "The Earth's Radiation Zones."

Since heat may be transferred from one object to another only by conduction, convection or radiation, therefore by measuring the temperature of the isothermal region of the atmosphere, in which both conduction and convection are small, it is possible to determine the radiation intensity of the earth at as many places as one may wish.

The effective radiating level, as determined by Abbot and Fowle, has an average elevation of about 4 kilometers, consequently the lower clouds are within the radiating surface while the cirri are above it. Hence the latter and they alone can strongly affect the intensity of the outgoing radiation.

An extensive exploration of the upper atmosphere with sounding balloons has shown that, probably because of the unequal distribution of cirri, the intensity of the earth's escaping radiation within the tropics is to that of latitudes 35° to 60° approximately as 3 to 4. In fact as a radiator the earth has an inefficient equatorial zone, efficient zones of middle latitudes, and finally, for which there is some evidence, inefficient polar caps.

12. W. J. HUMPHREYS. "The Amount and Vertical Distribution of Water Vapor on Clear Days."

It is important to any one using a bolometer, or a pyrheliometer, to know the approximate amount of water vapor through which the radiation reaching his instrument has passed. In attempting to determine this amount the records have been brought together of 74 balloon flights, made on cloudless days, or such as were adapted to the ordinary use of the bolometer.

According to these data the amount of water vapor per unit volume decreases with elevation on *cloudless* days in an approxi-

mate geometric ratio, and the thickness of the water layer that would result from a condensation of all the water vapor in the atmosphere on such days above any given level may be approximately expressed by the equation

$$d = 2\,e$$

in which d is the depth of the water layer in millimeters, and e the partial pressure of the water vapor, at the place of observation, in millimetres of mercury. This value is about 13 per cent less than that given by Hann for all sorts of days, and heretofore commonly used in bolometric work.

13. Miss Sarah F. Whiting. "Daytime Laboratory Work in Astronomy."

Miss Whiting made a plea for better organisation of the work of teaching elementary astronomy. She contended that it should be made as perfect as laboratory physics, which thirty years ago was in the same condition that astronomy is in now. A brief outline of suitable exercises and the material required in them was presented. These included maps of the moon, photographs of the stars, celestial globes, etc. Miss Whiting recommended the appointment of a committee to investigate the teaching of elementary astronomy and to report upon it.

Professor Doolittle favored such action; and at a later stage a committee was appointed, consisting of Miss S. F. Whiting, C. L. Doolittle, John A. Miller and C. A. Chant.

14. Frank W. Very. "On Scales of Intensity for the Lines of the Solar System."

By means of his spectral-comparator Professor Very has investigated an absolute scale of intensity. Rating as 10, a spectral line not appreciably broader than an image of the slit and perfectly black, the strength of any line in absolute units is the product of its width and the intensity of its absorption, multiplied by a constant. From a smooth curve which represents the true photometric intensities of ultra-violet lines on negatives by Higgs, the meaning on this scale of Rowland's symbols was investigated.

Professor Very found that Pickering's method of measurement (H. C. O. *Annals*, Vol. VIII., pp. 207-219) yields intensities in agreement with the absolute values through a middle range but they are discordant at the ends of the scale. He also stated that differences of width of spectral lines have been exaggerated in Thollon's *Atlas*.

15. Miss Henrietta S. Leavitt. "Periods of Variable Stars in the Magellanic Cloud."

The periods of 25 of the variable stars (usually of magnitudes 11 to 15) in the Small Magellanic Cloud have been determined, and have been found to vary from 1¼ to 127 days, while the light-curves are of the "cluster," sometimes called the "ant-algol," type. The brightness and the length of the period are so closely related that if one is known the approximate value of the other may be inferred. The fainter stars have the shorter periods. For a variation of one magnitude in brightness at maximum or minimum the logarithm of the period increases by about 0.48.

16. S. A. Mitchell. "The Radial Velocity of 96 Herculis."

From a study of radial velocities obtained from spectrograms taken at several observatories Professor Mitchell finds the system of this star very complicated. At first it was thought to consist of three bodies, but present indications suggest that it contains four bodies.

17. R. H. Tucker. "The San Luis Observatory of the Carnegie Institution.

The object of this undertaking of the Carnegie Institution was to make measures of the positions of the stars down to the south pole, thus completing for the entire celestial sphere the work which had been begun by Boss at Albany. Professor Tucker obtained leave of absence from the Lick Observatory, and went out in July, 1908. The meridian circle used was the very one by which the measurements had been made at Albany. The observatory was located on the grounds of the Government

DISEMBARKING AT WAKEFIELD

THE SESSION IN THE PINE GROVE

Normal School, surrounded by fields of alfalfa. The work of observing was begun in April 1909, and although it was expected to take three years, yet by thorough organisation it was completed in less than two. In the first year 62,000 observations were made, and when the work ceased in January, 1911, over 85,000 observations had been made. The Argentine Government treated the members of the expedition with great courtesy, admitting their instruments and supplies without examination by the customs authorities and assisting them in many ways. To commemorate the work a special medal was struck, and this was presented to Professor Tucker at a banquet held just before leaving the country.

18. C. C. Smith. "A Short Formula for the Computation of Circummeridian Azimuths."

The ordinary formula for azimuth requires the use of a subtraction logarithm. In the short formula $1 + \cot \delta \tan \phi \cos t$ is expanded in a series, and after re-arrangement and reduction gives a formula for azimuth which requires the looking-up only of the natural logarithm after which the multiplications may be quickly carried out on the arithmometer. The formula is much shorter and gives less chance for error than the ordinary formula, especially where a considerable number of observations have been taken at each station.

19. R. M. Stewart. "Changes in Collimation and Level of the Ottawa Meridian Circle."

This paper deals with the observations made at Ottawa from March to December, 1910. Measurements of collimation and level were made usually twice in the course of an evening's work; the changes during the interval (four hours on the average) are here investigated. The average change of collimation was $+ ''\cdot 03$ for Clamp East and $- ''\cdot 20$ for Clamp West; these changes run with great regularity, changing invariably with the reversal of the instrument, and appear to be entirely independent of seasonal and temperature changes or of the interval between the observations. The changes of level were not sensibly affected by

reversal of the instrument, but there is some evidence of a small seasonal effect.

20. J. S. PLASKETT. Preliminary Measures of the Solar Rotation."

This paper is a first contribution towards the scheme of co-operation in determining the solar rotation by the Doppler displacement of the spectral lines, which was organised at the meeting of the Solar Union at Mt. Wilson last September. A large amount of preliminary work has been performed for the purpose of ascertaining the most suitable apparatus and methods for accurate work. The mean of 14 rotation plates, obtain in June and July of the present year, gives, at the equator, a velocity of 2·035 km., about 1 per cent less than Adams' values. The measures of upwards of 40 spectra, in the region allotted to this Observatory, λ5500-λ5700, give no definite indication that the velocity due to any particular lines or elements differs from that of the general reversing layer. Further measures of plates, having impressed upon them an arbitrary displacement of the same magnitude and character as the rotation plates, show that the small varying displacements of different lines is of the same order as those obtained above and is probably mostly due to the character for measurement of the line itself and not to differences in the velocity.

21. E. E. BARNARD. "Preliminary Report on the Negatives of Halley's Comet taken by Mr. Ellerman at Honolulu.

Nothing abnormal has so far appeared.

22. FREDERICK SLOCUM. "The Solar Prominence of October 10, 1910."

This was an account, illustrated with lantern slides, of a fine prominence which exhibited very rapid and otherwise notable changes.

23. OLIVER J. LEE. "Vapor-Density Effects on the Calcium Lines *H*, *K* and *g*."

24. EDWIN B. FROST. "Radial Velocity of Halley's Comet as Derived from a Spectrogram."

It is not easy to secure a spectrogram suited to such a purpose, but from one obtained on May 24, 1910, with one prism, a velocity of + 55 km. per sec. was deduced which agreed very well with the velocity 56 km. per sec. computed from the ephemeris.

25. S. I. BAILEY. "Note on the Magnitude of the Stars in Messier 3.

In the cluster 47 Toucani there is a lack of stars of medium magnitude, a fact which has been noticed by others. The stars seem to be divided into two distinct groups, those comparatively bright and those very faint, with a decided lack of those of medium brightness. There are many variables amongst the stars. In all there are, perhaps, 60,000 stars, the brightest being of magnitude 10 and the faintest of magnitude 21.

26. S. ALBRECHT. "Tables of Effective Wave-Lengths in Stellar Spectra."

Professor Albrecht finds that the wave-length for the same line varies from one stellar type to another.

27. S. ALBRECHT. "Wave-Lengths of the Silicon Lines 4552·7, 4567·9 and 4574·9 in Stellar and in Laboratory Spectra."

28. S. ALBRECHT. "On Fundamental Systems of Wave-Lengths, Especially for *B*-Type Stars."

29. HENRY NORRIS RUSSELL. "Photographic Determination of the Position of the Moon."

The method proposed is to occult the moon by a disc on the end of a rod projecting above the objective of the telescope and obtain the image of the stars in the field. Then the plate is exposed to the moon for about 0·2 sec. In this way the position of the moon can be measured from the stellar images. A beautiful photographic print was shown illustrating the method, and it was stated that positions obtained by it are as accurate as those secured in the best meridian work.

30. A. E. DOUGLASS. "Note on the Ellicott Astronomical Instruments."

This was a description, illustrated by photographs, of some famous instruments, now in the National Museum at Washington, constructed about 1780 to 1790 by Andrew Ellicott, of Philadelphia. They include a zenith sector used in many important boundary determinations in the United States; a transit and equal altitude instrument; an upright quadrant, and others. Professor Douglass expressed the hope that other old and worthy instruments may be rescued from obscurity and preserved in the same museum.

The Society adjourned at 3.50 p.m. on Friday, after which the members were taken for a drive which lasted until 6.30. The driveway of the Ottawa Improvement Commission, "Lower Town," Rideau Hall grounds, Rockliffe Park, Inter-provincial Bridge, Hull, Parliament Buildings and other interesting features were visited and drew forth many expressions of admiration.

That evening and next day the visitors left the Capital, many taking trips down the St. Lawrence or westward through Toronto.

The Society will meet at Washington, D.C., in December next, in conjunction with the American Association for the Advancement of Science, but the next annual meeting will be held in August, 1912, at Pittsburg, Pa.

NOTES FROM THE DOMINION OBSERVATORY

ASTROPHYSICS

Work in determining the rotation period of the sun by the displacements of the spectrum lines at opposite limbs has been actively prosecuted since last May, when a new 6-inch plane grating ruled by Dr. Anderson at Johns Hopkins University, Baltimore, was received. This grating which has a ruled surface 9·6 × 12·7 cm., 75038 lines, 15000 to the inch, gives excellent definition in the first four orders, produces bright spectra, and is very free from diffused light and ghosts. It is especially in this last respect, freedom from diffused light, that it excels the grating previously employed. This is important in the measurement of the line displacements on which the determination of the solar rotation depends, for if the lines are partially blocked up the measures are neither so easily nor so accurately made as when there are strong contrasts between the lines and the continuous spectrum. This grating, like the previous one, has some astigmatism, and for the best results in rotation work it is necessary to occult part of the length of the ruling.

Three series of rotation plates have so far been obtained in two regions of the spectrum. According to the scheme of coöperation arranged at the meeting of the International Union for Coöperation in Solar Research, held at Mt. Wilson in September, 1910, each of the observatories taking part in this work was allotted a certain limited region, about 200 tenth-metres, of the spectrum for observation, and in addition each was to secure plates from a common or general region observed by all. This

general region is in the violet λ4220-4280, the same region used by Adams at Mt. Wilson in his recent work on the Solar Rotation. The special region allotted to the Dominion Observatory is in the yellow-green λ5500-5700. Of this region two series of plates have been secured, the only difference in the two series being in the distance from the sun's limb at which the spectra were obtained. Of the general region one series has been obtained.

The measurement of these plates, which, owing to their number and to the number of lines on each, is an arduous undertaking, is well under way, and it is hoped that not only will the value of the rotation period for different latitudes soon be determined, but other interesting and important results will be secured. Until the measures are completed and reduced, however, no final values can be given.

The period of the Spectroscopic Binary B. A. C. 5890, R. A. $17^h\ 21^m$, Dec. $-5°\ 0'$, F type, Phot. Mag. 4·9, which has been under observation here since 1909, has been determined by Mr. Parker as approximately 25·8 days. This star has a composite spectrum, both components of about the same intensity and type, and it is only at one part of the velocity curve that separation occurs. At other phases with the dispersion used here the spectra are blended, and the form of the velocity curve and the elements of the orbit will be difficult of determination.

J. S. P.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

August, 1911

Temperature — In the extreme southwest of British Columbia mean temperatures were either normal or a little above, but over the remainder of the province, from 1 to 2 degrees below. Throughout the Prairie Provinces generally, the month was cooler than usual, with mean temperature from 3 to 5 degrees below average in Alberta and Saskatchewan, and 2 to 3 degrees below in western Manitoba. In the eastern portion of the latter province, however, temperature conditions were nearly normal.

In the Lake Superior districts of Ontario the difference from average was very small, but over the rest of the province temperatures exceeded the normal by about 2 degrees.

The mean temperature for the month exceeded the average by 3 degrees in Quebec, and by from 1 to 2 degrees in the Maritime Provinces.

Precipitation — The precipitation recorded during August was in excess of the normal amount in British Columbia, the Western Provinces, the southern counties of the Peninsula of Ontario and in New Brunswick. Less than the normal amount was reported from the greater part of Ontario, Quebec, Nova Scotia and Prince Edward Island. Exceptionally heavy rainfalls occurred locally during the first week, in Alberta and Manitoba.

September, 1911

Temperature — Cool weather characterized September throughout Canada, and sharp frosts occurred at intervals in

many localities. The mean temperature for the month was subnormal, except in far northern districts of British Columbia, the Yukon Territory, and very locally in the Peninsula of Ontario, where the average was just reached or slightly exceeded. Departures from normal were pronounced in southern parts of the Western Provinces, northern Ontario, and the greater part of Quebec and northern New Brunswick, being generally over 3 degrees.

Precipitation — Precipitation was generally deficient in British Columbia, western Alberta, southern Saskatchewan, Ontario, except west of Port Arthur, the greater part of the Peninsula, and the eastern counties, the Gaspé Peninsula and northeastern New Brunswick. In other parts of Canada the amount recorded exceeded the average with heavy falls in Manitoba, southern New Brunswick and Nova Scotia.

Temperatures for August and September, 1911

Station	August		September	
	Highest	Lowest	Highest	Lowest
Yukon				
Dawson	81	30	77	12
British Columbia				
Atlin	72	36	66	24
Agassiz	84	42	80	40
Barkerville	80	32	64	18
Kamloops	90	42	88	30
New Westminster	83	47		
Prince Rupert	80	44	80	30
Vancouver	80	48	74	36
Victoria	80	46	73	38
Western Provinces				
Battleford	84	32	76	26
Broadview				
Calgary	78	32	74	22
Carman	88	39	77	27
Edmonton	82	33	77	20
Medicine Hat	92	30	84	28
Minnedosa	85	32	76	20
Moose Jaw	88	30	82	26
Oakbank	84	38	72	26
Portage la Prairie	86	37	75	29
Prince Albert	84	34	73	24
Qu'Appelle	82	30	79	26
Regina	83	32		
Swift Current	86	32	83	24
Winnipeg	88	40	76	30
Ontario				
Agincourt	91	45	87	31
Aurora	91	36	85	27
Bancroft	91	32	81	26
Barrie	86	42	81	30
Beatrice	90	31	80	22
Birnam	89	40	88	35
Bloomfield	90	43	78	32
Brantford	94	44	87	32
Bruce Mines	83	37	78	24
Chatham	94	41	91	40
Clinton	91	43	80	31
Cottam	94	39	90	31
East Toronto				
Gravenhurst	88	31	81	24
Guelph	89	41	83	30
Haliburton	96	31	81	23
Hamilton				
Huntsville	88	35	80	24
Kenora	89	37		
Kinmount	87	33	79	23
Kingston	86	46	75	30
Lakefield			80	31
London	95	39	88	32
Lucknow	90	37	83	30
Madoc	93	39	83	28
Midland	88	65	85	55
North Gower		38	82	24
Otonabee				
Ottawa	90	43	85	31
Owen Sound		39	79	37
Paris	94	43	88	32
Parry Sound	90	38	80	28
Peterboro'	87	39	84	28
Port Arthur	81	35	75	24
Port Burwell	85	45	76	38
Port Dover	87	45	83	36
Port Stanley	86	43	77	36
Ronville	86	34	80	26
Sarnia				
Southampton	92	40	87	31
Stonecliffe	91	38	80	24
Stony Creek	94	46	88	33
Stratford				
Toronto	90	47	87	34
Uxbridge	89	38	82	28
Wallaceburg	93	42	88	30
Welland	92	48	84	36
White River	82	31	72	14
Quebec				
Brome	88	36	77	27
Father Point	81	40	68	25
Montreal	90	48	74	34
Quebec	88	44	71	30
Sherbrooke	89	42	77	27
Maritime Provinces				
Charlottetown	90	44	75	32
Chatham	92	43	76	30
Dalhousie	87	45	76	31
Fredericton	88	40	74	26
Halifax	82	48	74	32
Moncton	87	39	75	27
St. John	80	50	71	35
St. Stephen	88	41	79	23
Sussex	86	42	75	24
Sydney	86	40	74	35
Yarmouth	80	48	75	33

Earthquake Records by the Milne Seismograph

TORONTO

R. F. Stupart, Director.

P.T. = Preliminary Tremors. L.W. = Large Waves. Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1911	P.T. Comm. h m	L.W. Comm. h m	Max. h m	End. h m	Max. Amp. mm	Durat. h m	Remarks
1028	Aug. 16	23 1·6?	23 10·9	23 42·7	2 7·3	2·0	3 5·7	Beginning preceded by air currents
		23 5·5	B 23 39·7				3 1·8	
1029	" 21	16 53·1		16 54·7	17 38·6	0·3	0 45·5	Thickenings
1030	" 27	No P.T's.	11 12·4	11 14·9	11 35·1	0·8	0 22·7	Small
1031	" 29	3 58·6	4 1·2	42·2	4 18·6	1·0	0 20·0	Small
1032	Sept. 6	1 3·2	1 19·0	1 19·4	1 43·8	0·15	0 40·6	A. T. preceding [P. T's.
		1 16·4						
1033	" 13	3 23·5	3 30·6	3 34·0	4 15·7	0·5	0 52·2	Very small
		3 28·5						
1034	" 15	13 17·0	13 29·9	13 30·8	14 53·8	0·8	1 36·8	Vib. increased at [13h 29m·9
		20·6						
1035	" 17	3 38·7	3 47 2?	4 12·0	6 32·0	4·9	2 53·3	Medium
			3 49·7					
1036	" 20	5 38·0		5 43·?	6 33·0	0·2	0 55·0	
		40·0						
1037	" 22	5 15·9	5 24.1	5 27·8	6 20·3	0·7	1 04·4	
1038	" 22	6 31·8			6 34.0	0·1	0 2·2	

Period 14·7 seconds. 1 mm. = 0″·64.

VICTORIA, B. C.

E. B. Reed, Superintendent.

No.	Date 1911	P.T. Comm. h m	L.W. Comm. h m	Max. h m	End h m	Max. Amp. mm	Durat. h m	Remarks
1043	Aug. 16	22 53·7	23 4·2	23 30·5	24 45·9	1·2	1 52·2	Small
		22 58·6	B 23 23·6					
1044	" 21	16 42·4		16 43·3	16 44·6	0·1	0 4·2	Thickening
1045	" 21	No P.T's.	16 50·7	16 50·7	18 0·0	1·0	1 9·3	Beg. with sod. vib. [may be part of pre-
1046	" 27	11 22·6	11 25·3	11 26·4	11 32·8?	0·3	0 10·2	[vious disturbance
1047	Sept. 6	1 13·0	1 20·0	1 20·6	1 39·1?	0·2	0 26·1?	[ments doubtful
1048	" 13	3 7·0?	3 14·4	3 18·4	3 33·3	0·5	0 26·3	F't. trace. Measure-
1049	" 15	Trace too faint to measure		13 26·0?				Tr. so weak and dis- [col'd impos. to get [begin. and ending.
1050	" 17	3 31·3?	3 40·9	3 55·5	5 58·0	4·9	2 26·7	Med. Weak trace P.
		35·3	3 43·3					[T's, doubtful
1051	" 20	5 24·0	5 28·7	5 30·5	5 56·7	0·3	0 32·1	Thick'ing increased [at 5h. 30m·2
1052	" 22	5 5·9	5 9·4	5 11·7	6 5·0	0·9	0 59·1	
1053	" 22	6 23·3			6 24·5	0·05	0 1·2	[off. L. earthquake
1054	" 20	2 44·6		2 44·8	2 48·3	0·5	0 3·7	Sod. vib. Grad. tap.

Period 15 seconds. 1 mm. = 0″·76

I. V.

MAGNETIC OBSERVATIONS

During the months of August and September the magnetic forces, as shown by the photographic curves, were remarkably steady. One moderate disturbance was recorded in each month, that in August occurring from the 23rd to the 26th and that in September from the 19th to the 22nd. In each case the maximum and minimum for the month was recorded during the disturbance.

Declination

Month	Mean of Month	Max.	Date	Min.	Date	Monthly Range	Amplitudes—Mean Daily: From hourly readings	Amplitudes—Mean Daily: From Means of Extremes
1911	° ′	° ′		° ′		° ′	° ′	° ′
Aug.	6 13·7	6 31·5	26	5 27·0	23	4·5	0 13·2	0 19·2
Sept.	6 13·9	6 44·5	20	5 35·5	19	1 9·0	0 11·3	0 17·1

Bifilar

	C.G.S. units							
Aug.	·16208	·16298	23	·16060	23	·00238	·00049	·00068
Sept.	·16196	·16243	19	·15970	20	·00273	·00039	·00062

Inclination

Month	Mean
	° ′
August	74 38·1
September	74 38·8

ASTRONOMICAL NOTES

STELLAR DISTRIBUTION AND MOVEMENTS.—From a paper by A. S. Eddington before British Association for the Advancement of Science, 1911, Section A. "Properly considered, I think that this relation of spectral type and velocity is one of the most startling of the results of modern astronomy. For the last forty years astrophysicists have been studying the spectra, and forming their systems by which they arrange the stars in order of evolution. However plausible may be their arguments, one would have said that their hypotheses must be for ever outside the possibility of confirmation. Yet, if this result is right, we have a totally different criterion by which the stars are arranged in the same order. If it is really true that the mean motion of a class of stars measures its progress along the path of evolution, we have a new and most powerful aid to the understanding of the steps of stellar development.

These facts direct attention to the very fundamental question. How must we account for the individual motions of the stars? It appears that, as we trace back the life-history of a star, its velocity is found to be smaller and smaller; in the Orion stage it was barely a third of what it will ultimately become. It seems right to infer that stars are born with little or no individual motion. If we suppose that the gravitational attraction of other stars produces the motion which is subsequently developed, there are two possibilities open: either it may be the casual interference of the neighboring stars, or it may be the combined average pull of the whole matter of the universe, that is instrumental in producing the motions. There is one important observational fact. In the Taurus cluster, and again in the Ursa Major stream,

stars which are well advanced in evolution have evidently preserved throughout their lifetime equal and parallel motions, notwithstanding that they are moving through space occupied by stars not belonging to their system. Unless this is due to some exceptional circumstance, the existence of clusters such as these seems necessarily to prove that the forces which produce the individual velocities of stars are nearly constant over large volumes of space (large compared with the distance of one star from its neighbor). Hence it is the central attraction of the universe as a whole, and not the attraction of the immediate neighbors, that is effective in changing a star's velocity. This is in accordance with numerical calculation, which shows that a single star, even if approaching very closely, can have but little influence. We might have expected that, if the motions of stars are due to the resultant force of the universe, there would be more definite traces of a centre of gravity, and the velocities would be generally radial ; but it must be remembered that we cannot attribute a centre of gravity to the stellar system — it does not act as though its mass were concentrated at one point."

Jupiter in a Large Telescope.— The planet viewed through the great telescope at Meudon Observatory, France, by T. E. R. Phillips, *Observatory*, No. 440.

The ease with which delicate and ordinarily difficult features were seen. Many of them did not require to be searched for, but obtruded themselves upon the vision and could be held with surprising steadiness. The region presented to view on June 29th contained the great S. tropical disturbance, in which I had previously observed with my 12¼-inch Calver reflector a remarkable series of sharp points and serrations along the S. edge of the S. equatorial belt. These were seen with the greatest ease and distinctness in the large telescope, and many other features which I had previously detected with some difficulty in the smaller instrument were readily confirmed. Moreover, the aspect of the equatorial zone proved that faint spots and slight differences of shade gain considerably with increase of aperature.

The great resolving power of the instrument.—Spots which I had previously observed as *simple* were shown to possess a highly *complex* structure, and the belts appeared more irregular and knotted than I had ever previously seen them. It was abundantly evident that there is a vast amount of minute detail on the planet which can only be revealed by instruments of great separating power.

THE CANALS OF MARS.—"A word or two on the so-called 'canals' may not be out of place here. Using a 9¾-inch, on 1896 June 12, the writer glimpsed the Læstrygon as a straight black line, for a quarter of a second, on a disc of 6″·7; but on 1909 November 5, with the 32·7-inch, on a disc of 17″·0, he held steadily the sinuous curves and knots of the same streak. Again, on 1878 February 28, Schiaparelli glimpsed with an 8½-inch, the Hiddekel as a straight line, on a disc of 5″·5; but on 1909 November 3, on a disc of 17″·4, Professor Hale saw this streak, with the large mirror, as a broad, curved marking, and further resolved it into 'minute, curved, and twisted filaments.' Considering the distance of Mars in these cases, and the separating powers used, we find, for the Læstrygon, that Mars was seen at Meudon on 1909 November 5, as far as definition is concerned, as if it were almost nine times nearer the earth than at Juvisy on 1896 June 12; and that it appeared, for the Hiddekel, on 1909 November 3, at Mount Wilson, as if it were some fifteen times nearer the earth than at Milan on 1878 February 28. But it is a truth which nobody will question, that a celestial body is better seen when near the earth than when far removed from it. Hence the fact that irregular streaks held steadily in perihelion opposition are glimpsed as straight lines when Mars is practically nine or fifteen times more distant establishes the illusive character of the straight 'canals' as objective realities on the planet, and demonstrates the perfectly natural appearance of Mars."—E. M. Antoniadi in the *Monthly Notices of the Royal Astronomical Society*, No. 8, June, 1911, pp. 715-716.

J. R. C.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

Query

As far as can be estimated, what are the relative sizes of the principal stars? —T. H. W.

Answer

An answer to the above query was requested from the Dominion Observatory, at Ottawa, and Mr. J. B. Cannon, of the staff in astrophysics, has, at the expense of much thought and labor, furnished the following able contribution. In it not only are tables given which contain the information asked for, but Mr. Cannon indicates at some length the manner in which these results are obtained.

THE DIAMETERS OF THE STARS

The question of the diameters of the stars is one which can be answered only by means of assumptions which are more or less plausible, and the results thereby arrived at can only be looked upon as being, to a large extent, very uncertain.

In order to be able to say anything about the diameter of one of the stars it is necessary to have some knowledge of three things:—(*a*) parallax, (*b*) magnitudes and (*c*) surface intensity. —to say nothing of absorption in space. From the parallax we get the distance of the star from us, distance and magnitude give luminosity, and luminosity and brightness give the surface area of the star. The sun is taken as unit in each case. Thus, having the surface of the star in terms of the sun's surface, we have at once the ratio of the radii of the star and the sun.

Now in three cases, viz.:—Algol, β Aurigæ and α Herculis,

which have been attacked spectroscopically, the radii, masses and densities have been computed from the data thus obtained. From these results we obtain the surfaces of the stars and hence, having the luminosity, we arrive at a probable value for the intrinsic brightness or surface intensity. An example may, perhaps, be the best way to make clear the method of arriving at the luminosity of any star.

α Orionis has a parallax of $0''{\cdot}03$.

$$\text{Its distance from the earth therefore} = \frac{3{\cdot}26}{{\cdot}03} \text{ light years,}$$

$$= 109{\cdot}00 \text{ light years.}$$

The magnitude of α Orionis is 0·91.

Now we know that the light-ratio between successive magnitudes is $\sqrt[5]{100}$, or the number whose logarithm is ·4.

We have, therefore,

$$\log b_n - \log b_m = -\frac{4}{10}(n - m),$$

where b_n and b_m are the brightnesses, respectively, of stars of the nth and mth magnitudes. Taking a tenth magnitude star as the unit, we get

$$\log b_n = -\frac{4}{10}(n - 10),$$

$$= 4 - 0{\cdot}4\, n.$$

Using this formula, we get for the light of α Orionis

$$\text{log of brightness of } \alpha \text{ Orionis} = 4 - 0{\cdot}4\,(0{\cdot}91)$$

$$= 3{\cdot}636.$$

Now the luminosity is equal to the light multiplied by the distance squared.

Hence, in terms of the sun's luminosity, we have

$$\text{Luminosity of } \alpha \text{ Orionis} = \frac{\log^{-1} 3{\cdot}636 \times [109 \times 365 \times 24 \times 60]^2}{\log^{-1} 14{\cdot}52^* \times [8]^2}$$

$$= 670\ \odot$$

where $\odot$ denotes the luminosity of the sun.

* These are obtained from taking $-26{\cdot}3$ for the sun's magnitude and 8 light-minutes for its distance from the earth.

The luminosities used in the table which follows were taken from Kapteyn and Weersma's publication mentioned hereafter. They obtained them from the formula

$$\log L = 0{\cdot}200 - 0{\cdot}4\, m - 2 \log \pi.$$

This is the same as that used above as will be seen from the formula,

$$\log L = \log \left(\frac{\text{brightness of star}}{\text{brightness of sun}} \right) \times \left(\frac{\text{distance of star}}{\text{distance of sun}} \right)^2,$$

$$\text{or } \log L = (4 - 0{\cdot}4\, m) - (4 - {\cdot}4\, m \text{ of sun}) \times \left(\frac{\text{distance of star}}{\text{distance of sun}} \right)^2.$$

Now the sun's magnitude was taken as 5·5 at a distance at which the parallax is 1″.

Hence the formula becomes

$$\log L = (4 - 0{\cdot}4\, m) - [4 - 0{\cdot}4\,(5{\cdot}5)] + \log \left(\frac{\frac{3{\cdot}26}{\pi''}}{\frac{3{\cdot}26}{1''}} \right)^2,$$

$$= 0{\cdot}22 - 0{\cdot}4\, m - 2 \log \pi.$$

Having then a star of any type whose surface intensity is known and whose radius is known we are in a position to speculate as to the radii of other stars of the same type. For other types we have to assume some relation between the surface intensity of the various types and that of the sun. That is what has been done here.

The star which was taken as a standard to work from is β Aurigæ, discussed by Stebbins in the *Astrophysical Journal*, Vol. XXXII., p. 185, October, 1910. He has classed it as belonging to *Ap*, and has obtained the following results from the assumption of a parallax of 0″·03 : —

Radius of each component		2·58 ☉,
Mass of 1st		2·38 ☉,
Mass of 2nd		2·34 ☉,
Density of each		0·14 ☉,
Total light	greater than	80 ☉,
Surface intensity	greater than	12 ☉.

In the following, the classes have been grouped very liberally, *A* and *B* being taken together, as having the same surface intensity, viz., that given by Stebbins above for β Aurigæ, namely, 12 ☉; *F* has been taken as 3 ☉; *G* equal to ☉ and *K* and M one-half ☉.

The luminosities were taken from the *Publications* of the Astronomical Laboratory at Groningen, No. 24, (being a list of parallax determinations compiled by Professor Kapteyn and Dr. Weersma). In three cases, Algol and α and β Orionis, the luminosities were not given by them, these stars having parallaxes 0″·03 or lower, from which Kapteyn and Weersma consider no reliable values can be obtained. In these three cases the luminosities have been computed from the magnitude and parallaxes and expressed in terms of the sun.

CLASS I (TYPES *A* AND *B*) SURFACE INTENSITY = 12 ☉

Star	Luminosity	Radius
α Aquilæ (Altair)	12·3	1
α Canis Majoris (Sirius)	48·1	2
α Crucis	{ 122·0 { 76·6	{ 3) { 2.4)
α Eridani (Achernar)	350	5·4
α Leonis (Regulus)	423	6
β Leonis (Denebola)	12·2	1
α Lyræ (Vega)	158	3·6
γ Orionis (Rigel)	20614	41·5
ζ Ursæ Maj. (Mizar)	{ 159 { 39	{ 3·6) { 1·8)
β Persei (Algol)	238	4·5

CLASS II. (TYPE *F*) SURFACE INTENSITY = 3 ☉

Star	Luminosity	Radius
α Canis Minoris (Procyon)	9·68	1·8
α Ursæ Min. (Polaris)	102·	5·9

CLASS III. (TYPE *G*) SURFACE INTENSITY = ☉

Star	Luminosity	Radius
α Aurigæ (Capella)	300	17·3
α Centauri	2·03	1·4
γ Geminorum (Pollux)	127	11·2

CLASS IV. (TYPES *K* AND *M*) SURFACE INTENSITY = ½ ☉

Star	Luminosity	Radius
α Boötis (Arcturus)	230	21.4
α Tauri (Aldebaran)	224	15·0
α Orionis (Betelgeux)	524·3	32·4

A very interesting article appears in *Comptes Rendus* for January 9, 1911, in which M. Chas. Nordmann computed the values of the ratio $\frac{R_*}{R_\odot}$ from the following formula

$$\log \frac{R_*}{R_\odot} = \log \frac{d_*}{d_\odot} - \left[\tfrac{1}{5} (G_* - G_\odot) + \tfrac{1}{2} \log \frac{E_*}{E_\odot} \right],$$

where R_* and $R_\odot$ are the semi-diameters of a star and the sun, G_* and $G_\odot$ their magnitudes, d_* $d_\odot$ their distances from the earth and E_* and $E_\odot$ their intrinsic brightness. He finds the following values: —

Star	$\frac{R_*}{R_\odot}$	Value given above
Sirius	1·13	2
Procyon	1·35	1·8
Aldebaran	13·50	15·0
Capella	8·26	17·3
Vega	1·57	3·0
γ Cygni	0·92	. . .
α Persei	1·83	. . .
Polaris	1·93	5·9
β Andromedæ	13·00	. . .
ζ Persei	1·29	4·5

Considering the assumptions that were employed, the agreement between the results above must be regarded as very fair.

J. B. CANNON.

QUERY

Is Venus ever occulted by the moon? — D. J. H.

ANSWER

Yes: Venus is occulted by the moon, as in the case of the other planets, I am not aware that a table giving the times of these occurrences has ever been calculated.

Referring to occultations of Venus, Denning in his "Telescopic Work for Starlight Evenings," (p. 153) says:—"An occultation of this planet by the moon appears to have been recorded by the Chinese on March 19, 361 A.D. Tycho Brahe witnessed a similar phenomenon on May 23, 1587. Mœstlin observed Venus occult Regulus on September 16, 1574; and on October 2, 1590, this planet appears to have passed over Mars. Visible occultations of Venus are somewhat rare; they usually occur in daylight. A phenomenon of this kind was witnessed on December 8, 1877, over all the west part of the United States; and Professor Pritchett, of Missouri, says: 'The interest taken in it was shared alike by the educated and the illiterate, and even by children.' The evening was cloudless, and many persons noted the time of disappearance of Venus as seen by the unassisted eye."

Flammarion in his "Popular Astronomy" (English translation, pages 135-6) describes and illustrates an occultation which took place on October 14, 1874, at 3 p.m., in full sunshine.

C. A. C.